European Commission

# Preparatory study on lighting systems
## 'Lot 6'

*Specific contract N° ENER/C3/2012-418 Lot 1/06/SI2.668525*
*Implementing framework contract ENER/C3/2012-418 Lot 1*

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| | |
|---|---|
| AECI | Annual Energy Consumption Indicator |
| BACS | Building Automation Control Systems |
| BAT | Best Available Technology |
| BAU | Business as Usual |
| BGF | Ballast Gain Factor |
| BNAT | Best Not Yet Available Technology |
| BPIE | Buildings Performance Institute Europe |
| BR | Ballast Reliabilty |
| By | LED luminaire gradual failure fraction |
| cd | candela |
| CECAPI | European Committee of Electrical Installation Equipment Manufacturers |
| CEN | European Committee for Normalisation |
| CENELEC | European Committee for Electro technical Standardization |
| CFL | Compact Fluorescent Lamp |
| CIBSE | British Chartered Institution of Building Service Engineers |
| CIE | International Commission on Illumination |
| CL | Correction factor for over-lighting |
| CLO | Constant Light Output |
| CSES | Centre for Strategy & Evaluation Services |
| Cz | LED luminaire catastrophic failure rate |
| DALI | Digital Adressable LIghting |
| DFF | Downward light Flux Fraction |
| DLOR | Downward Light Output Ratio |
| DLS | Directional Light Sources |
| DMX | Digital Multiplexing |
| DoE | Department of Energy |
| DP | Lighting power density indictor |
| EC | European Commission |
| EED | Energy Efficiency Directive |
| EEE | Electrical and Electronic Equipment |
| Em | Maintained Illuminance |
| EN | European Norm |
| EPBD | Energy Performance of Buildings Directive |
| ErP | Energy-related Products |
| ETS | Emission Trading System |
| ETSI | European Telecommunications Standards Institute |
| EU | European Union |
| EuP | Energy-using Products |
| FBM | Ballast maintenance factor |
| FCL | Correction factor for over-lighting |
| Fhour | MELISA model light source hour factor |
| FLLM | Lamp Lumen Maintenance Factor |
| FLM | Luminaire maintenance factor |
| FLS | Lamp Survival Factor |
| Fphi | MELISA model light source luminous flux factor |
| FRSM | Room surface maintenance factor |
| Fsales | MELISA model Sales factor |
| FU | Utilization factor |
| Fy | LED module failure fraction |
| G | Giga, $10^9$ |
| GLS | General Lighting Service |
| GPP | Green Public Procurement |

| | |
|---|---|
| hEN | Harmonized European Product Standard |
| HID | High Intensity Discharge |
| Hz | Hertz |
| h/a | Hour per annum or year |
| I | luminous intensity |
| IEC | International Electrotechnical Commission |
| IES | Illuminating Engineering Society of North America |
| IP | Ingress protection |
| ISO | International Organization for Standardization |
| k | Kilo, $10^3$ |
| kred | power reduction coefficient for reduced level illumination |
| L | luminance |
| LE | LightingEurope |
| LED | Light Emitting Diode |
| LENI | Lighting Energy Numeric Indicator |
| LER | Luminaire Efficacy Rating |
| LERc | Luminaire Efficacy Rating Corrected |
| LFL | Linear Fluorescent Lamp |
| LLMF | Lamp Luminance Maintenance Factor |
| Lm | Maintained luminance |
| lm | lumen |
| LMF | Luminaire Maintenance Factor |
| LOR | Light Output Ratio |
| LPF | Lamp Power Factor |
| LSF | Lamp Survival Factor |
| lx | Lux |
| Lx | LED module rated life |
| M | Mega, $10^6$ |
| MEErP | Methodology for Ecodesign of Energy-related Products |
| MEEuP | Methodology for Ecodesign of Energy-using Products |
| MS | Member States |
| NDLS | Non-Directional Light Sources |
| NEEAP | National Energy Efficiency Action Plan |
| NEMA | National Electrical Manufacturers Association |
| NGO | Non Governmental Organisation |
| NRE | Non Residential |
| NZEB | Nearly Zero energy building |
| OLED | Organic Light Emitting Diode |
| P | Peta, $10^{15}$ |
| PDI | Lighting power density indictor |
| PE | Annual Energy Consumption Indicator |
| Pf, inv | MELISA model share of total EU-28 installed capacity (lm) involved in flux reduction |
| Pf, rem | MELISA model share of involved luminous flux remaining after system optimization |
| Ph, inv | MELISA model share of total EU-28 operating hours (fpe h/a) involved in hour reduction |
| Ph, rem | MELISA model share of involved operating hours remaining after system optimization |
| Pl | Maximum luminaire power |
| Pr | Rated lamp power |
| PRODCOM | Community Production |
| Ps,inv | MELISA model : share of total EU-28 sales of light sources involved in sales reduction |

| | |
|---|---|
| Ps,rem | MELISA model share of involved sales remaining after system optimization |
| Q0 | Average luminance coefficient |
| $R_a$ | Colour rendering index |
| REACH | Registration, Evaluation, Authorisation and Restriction of Chemical substances. |
| RES | Renewable Energy Sources |
| RLO | light output ratio |
| RLOW | light output ratio working |
| RoHS | Restricitons of Hazardous Substances |
| RSMF | Room Surface Maintenance Factor |
| SDCM | Standard Deviation Colour Matching |
| SME | Small and Medium Enterprise |
| sr | steradian |
| SSL | Solid State Lighting |
| T | Tera, $10^{12}$ |
| TBC | To be confirmed (only in draft versions) |
| TBD | To be defined (only in draft versions) |
| TBM | Technical Building Management |
| TC | Technical Committee |
| Tc | Colour Temperature |
| Tcp | Correlated Colour Temperature |
| tfull | annual operating hours of the full level illumination |
| TI | Threshold Increment |
| TOR | Terms of Reference |
| TR | Technical Report |
| tred | annual operating time of the reduced level illumination |
| U | Utilance |
| U0 | Illuminance uniformity |
| UF | Utilization Factor |
| UFF | Upward Light Flux Fraction |
| UGR | Unified Glare Rating |
| ULOR | Upward Light Output Ratio |
| UU | Useful Utilance |
| VITO | Flemish Institute for Technological Research |
| Wlamp | Nominal lamp power |
| y | year |
| XML | Extensible Markup Language |
| ηinst | Installation luminous efficacy |
| ηls | Luminous efficacy of a light source |
| ηp | Power efficiency of luminaires |
| Φn | Nominal luminous flux |
| Φr | Rated luminous flux |

Use of text background colours:
Blue: draft text
Yellow: text requires attention to be commented

# Executive summary

Comment: This report is currently a work in progress, as some parts of the study have not yet received the benefit of comments and data from stakeholders, therefore it should also not be viewed as a draft final report.

For a summary please consult the summaries of the current draft tasks at the beginning of each section.

# CHAPTER 0 Introduction

According to Article 16(1) of the Ecodesign Directive, the Commission adopted on 7 December 2012 a Working Plan for the period 2012-2014, setting out an indicative list of energy-related products which will be considered for the adoption of implementing measures for the following three years. The Commission established an indicative list of twelve broad product groups to be considered between 2012 and 2014 for the adoption of implementing measures. According to the principle of better regulation, preparatory studies will collect evidence, explore all policy options and recommend the best policy mix (Ecodesign and/or labelling and/or EPBD and/or self-regulation measures), if any, to be deployed on the basis of the evidence and stakeholder input. For some of the identified product groups, there is the possibility that overlaps exist with a number of on-going preparatory studies and regulations due for review. This is the reason why the list of product groups to be considered was split into a priority list and a conditional list.

Lighting systems are on the list of conditional product groups, where launching a preparatory study is dependent on the outcome of on-going regulatory processes and/or reviews. The scope of this study is to carry out a limited preparatory study on lighting systems for the exploration of the feasibility of Ecodesign, energy labelling, and/or energy performance of building requirements. The options of where to go next include a basic idea on how to implement possible measures, without going into detail. The energy saving potential of the options is considered, but not the political feasibility. The options can be further addressed in a possible full preparatory study.

This study follows the methodology for Ecodesign of energy-related products (MEErP) Tasks 0, 1-4 and partly 7.

The study builds upon existing Ecodesign and energy labelling legislation on lighting products (see 0.2).

## 0.1 Methodology for Ecodesign of Energy-related Products (MEErP)

Over the past 5 years MEEuP 2005 (Methodology for Energy-using Products version 2005) has been proven to be an effective methodology for Ecodesign preparatory studies. The MEErP 2011 Methodology Report therefore was intended to maintain the qualities of the former MEEuP methodology, extending the scope from energy-using products to energy-related products and providing more guidance to analysts and stakeholders involved in the Ecodesign preparatory studies.

The design of the methodology in the former MEEuP 2005 was enshrined in the Directive 2005/32/EC on Ecodesign of Energy-using Products. For the new Methodology for the Ecodesign of Energy-related Products (MEErP)[1] in 2011 it was proposed to follow the same route with the recast Directive 2009/125/EC on Ecodesign of Energy-related Products (hereafter 'Ecodesign directive').

The MEErP was thus developed in 2011 to contribute to the creation of a methodology allowing to evaluate whether and to what extent various energy-related products fulfil certain criteria that make them eligible for implementing measures under the Ecodesign Directive 2005/32/EC.

[1] http://www.meerp.eu/ VHK BV, Netherlands and COOWI, Belgium: Methodology Study Ecodesign of Energy-related Products, MEErP Methodology Report, under specific contract SI2.581529, Technical Assistance for the update of the Methodology for the Ecodesign of Energy-using products (MEEuP), within the framework service contract TREN/R1/350-2008 Lot 3, Final Report: 28/11/2011

More specifically, the MEErP tasks entail:
Task 1 – Scope (definitions, standards and legislation);
Task 2 – Markets (volumes and prices);
Task 3 – Users (product demand side);
Task 4 – Technologies (product supply side, includes both BAT and BNAT);
Task 5 – Environment & Economics (Base case LCA & LCC);
Task 6 – Design options;
Task 7 – Scenarios (Policy, scenario, impact and sensitivity analysis).

Tasks 1 to 4 can be performed in parallel, whereas 5, 6 and 7 are sequential (see Figure 0-1).

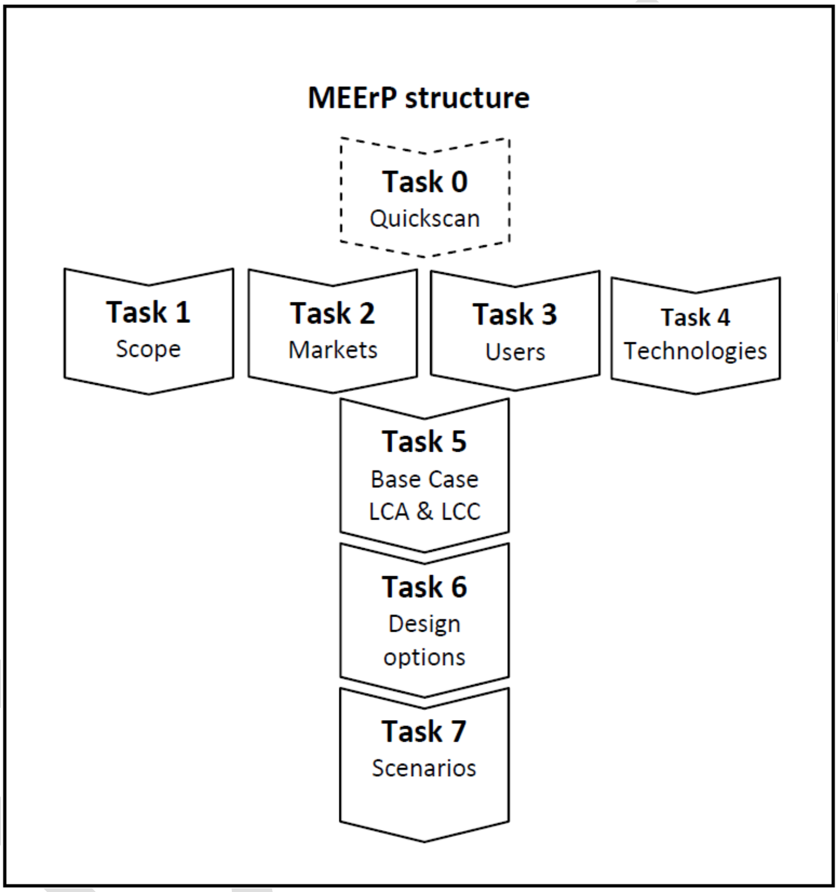


*Figure 0-1: MEErP structure*

The MEErP structure makes a clear split between:

- Tasks 1 to 4 (product definitions, standards and legislation; economic and market analysis; consumer behaviour and local infrastructure; technical analysis) that have a clear focus on data retrieval and initial analysis;
- Tasks 5 (assessment of base case), 6 (improvement potential) and 7 (policy, scenario, impact and sensitivity analysis) with a clear focus on modelling.

This study is conducted according to tasks 0, 1-4 and partly 7 specified in the tender specifications, including a meeting with relevant stakeholders.

## 0.2 Existing ecodesign and energy labelling legislation on lighting products

Three principal ecodesign regulations and two amendments related to lighting are in place today, all having a different specific scope:

- **Commission Regulation (EC) No 244/2009 of 18 March 2009** implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps.
- **Commission Regulation (EC) No 859/2009 of 18 September 2009** amending Regulation (EC) No 244/2009 as regards the ecodesign requirements on ultraviolet radiation of non-directional household lamps.
- **Commission Regulation (EC) No 245/2009 of 18 March 2009** implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council.
- **Commission Regulation (EU) No 347/2010 of 21 April 2010** amending Commission Regulation (EC) No 245/2009 as regards the ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps.
- **Commission Regulation (EC) No 1194/2012 of 12 December 2012** implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for directional lamps, for light emitting diode lamps and related equipment.

Also an energy labelling regulation regarding lighting is in place:

- **Commission Delegated Regulation (EU) No 874/2012 of 12 July 2012** supplementing Directive 2010/30/EU of European Parliament and of the Council with regard to energy labelling of electrical lamps and luminaires.

This study examines if the scope should be opened to lighting systems, if there are any issues left uncovered and if there are loopholes in the existing legislation. Both residential and non-residential lighting will be considered.

## 0.3 Lighting systems

Today the legislation only looks at light sources, luminaires and ballasts as a product. In this study it is the intention to also look at the application level. We want to adopt an extended product approach, looking at the lighting system as a holistic system comprising: light sources, ballasts, luminaires, or multiple luminaires in a system with sensors and controls and also the design and installation of the system.

In this context, lighting system means any energy-related device or system of devices used for the production of artificial lighting from the power supply in residential and non-residential lighting applications. A lighting system can therefore range from simple luminaires to large scale installations with multiple luminaires and intelligent controls such as in intelligent street lighting. Lighting systems can be placed on the market either with built-in lamps that are designed to be changed by the end-user, such as fixed LED modules, or with exchangeable lamps/without lamps. According to the EN 12655 standard a lighting system is defined as 'lighting equipment or lighting solution (lamps, ballast, luminaire and controls) required for the lighting scheme, its installation and operation during the life of the scheme';

Lighting schemes are the theoretical planning of a lighting system and allow for the evaluation of these systems at early stages. ‘Smart’ lighting systems are also included in this study. Lighting scheme design is a design process in which the lighting designer selects the lighting criteria for the place of interest, chooses the lighting solution, makes lighting calculations, configures the layouts, produces drawings of the lighting scheme and specifies the operating functions of the lighting system.

Some common descriptions of system components are[2],[3]:

- **Lamp**
  A light source made in order to produce optical radiation, usually visible;
- **Light source**
  surface or object emitting light produced by a transformation of energy
- **LED light source**
  electric light source based upon LED technology;
- **LED Lamp**
  technology LED light source incorporating one or more LED package(s) or LED module(s) and provided with one or more cap(s)[4]. Furthermore EN 62504:2014 requires that ‘A LED lamp is designed so that it can be replaced by an ordinary person as defined in IEC 600500-826, 826.18.03’;
- **Lamp cap**
  that part of a lamp which provides connection to the electrical supply by means of a lamp holder or lamp connector and, in most cases, also serves to retain the lamp in the lamp holder;
- **Lamp holder/ socket**
  A device which holds the lamp in position, usually by having the cap inserted in it, in which case it also provides the means of connecting the lamp to the electricity supply;
- **Ballast**
  a device connected between the electricity supply and one or more discharge lamps which serves mainly to limit the current of the lamp(s) to the required value;
- **LED control gear**
  unit inserted between the electrical supply system and one or more LED package(s) or LED module(s) which serves to supply the LED package(s) or LED module(s) with its (their) rated voltage or rated current;
- **Luminaire**
  An apparatus which distributes, filters or transforms the light transmitted from one or more lamps and which includes, except the lamps themselves, all parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting the lamps to the electric supply;
- **Dimmer**
  A device in the electric circuit for varying the luminous flux from lamps in a lighting installation;
- **Electrical switch**
  In general, a device for changing the electric connections among its terminals. In a lighting installation it can be a device that switches off the electrical supply, it can be electronic or mechanical;
- **Movement/presence detection sensor**
  A device that measures the light (light sensor) or that detects the movement/presence of persons (presence detection sensor);

[2] http://www.electropedia.org
[3] EN 12665 (2011)
[4] CIE DIS 024/E: 2015

- **Control and management unit**
  A unit that processes the received signals from switches and sensors and that manages the lighting in the installation by dimming or switching on and off;
- **Lighting communication network**
  A network throughout the building between lighting fixture and controls components, such as sensors and switches, which have bidirectional communication;

## 0.4 Key characteristics of lighting systems

Quality of light & lighting are of primary importance in many applications. Therefore lighting system design is usually based on minimum quality parameters as described in European standards such as EN 12464 Lighting of work places, EN 12193 Sports lighting and EN 13201 for Road lighting. Important parameters for specifying the lighting and the lighting system are briefly introduced in the next section. Terminology is defined in EN 12665.

### 0.4.1 Luminous flux of a light source

The primary performance parameter for a non-directional light source is luminous flux.

Luminous flux is the measure of the perceived power of light. It indicates the particular light output of a lamp or lighting system and is measured in lumens (lm). One lumen is the luminous flux of light produced by a light source that emits one candela of luminous intensity over a solid angle of one steradion. It is defined[3] as 'quantity derived from radiant flux Φe by evaluating the radiation according to its action upon the CIE standard photometric observer (unit: lm)'.

Unit: 1 lm = 1cd*1sr

*Figure 0-2: Luminous flux*

### 0.4.2 Luminous intensity

The primary performance parameter for a directional light source is luminous intensity.

Luminous Intensity (I) of a source in a given direction is the quotient of the luminous flux dΦ leaving the source and propagated in the element of solid angle dΩ, the corresponding unit is a candela [cd].

Unit: $1\ cd = 1\ \frac{lm}{sr}$

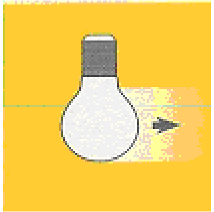

*Figure 0-3: Luminous intensity*

### 0.4.3 Illuminance

A primary performance parameter for providing light in an installation is illuminance. More details on a framework for the specification of lighting requirements is included in EN 12665.

Illuminance is the total luminous flux incident on a surface, per unit area. The SI unit for illuminance is lux (lx). One lux equals one lumen per square metre.

Unit: $$1\ lx = 1\ \frac{lm}{m^2}$$

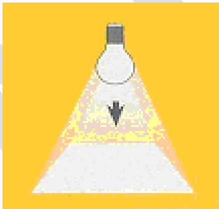

*Figure 0-4: Illuminance*

### 0.4.4 Luminance

The primary performance parameter for light emitted or reflected by an object is luminance. More details on a framework for the specification of lighting requirements is included in EN 12665.

Luminance is a photometric measure of the luminous intensity per unit area of light travelling in a given direction. It describes the amount of light that passes through or is emitted from a particular area, and falls within a given solid angle. The SI unit for luminance is candela per square metre [cd/m²].

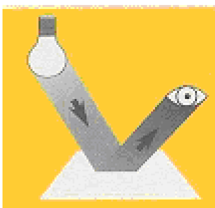

*Figure 0-5: Luminance*

### 0.4.5 Perceived colour

Setting lighting requirements on perceived colour is an important secondary performance parameter.

Perceived colour is defined[3] as an attribute of visual perception consisting of any combination of chromatic and achromatic content. This attribute can be described by chromatic colour names such as yellow, orange, brown, red, pink, green, blue, purple, etc., or by achromatic colour names such as white, grey, black, etc., and qualified by bright, dim, light, dark, etc., or by combinations of such names.

Primary parameters for specifying perceived colour requirements[3] are general colour rendering index (CRI, see 1.3.3), correlated colour temperature (CCT, see 1.3.3) and chromacity tolerances (see 1.3.3).

### 0.4.6 Glare

Setting requirements to prevent glare is also common practice and can provide important secondary performance parameters.

Glare is defined[2] as a condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or to extreme contrasts.

Disability glare may be expressed in a number of different ways, for example by values of threshold increment (TI) as defined in standard CIE 31. Discomfort glare may be expressed by means of a 'psychometric scale' derived from psychophysical experiments, for example by using the unified glare rating (UGR) as defined in standard CIE 117.

### 0.4.7 Important technical characteristics of the luminaires used

With reference to IEC 62722-2-1 on ‘Luminaire performance’ important technical characteristics of the luminaire are:

- Photometric code
- Rated input luminaire power (W)
- Rated Luminaire Luminous Flux (lm)
- LED Luminaire Luminous Efficacy (lm/W)
- Correlated Colour Temperature, CCT (K)
- Colour Rendering Index, CRI (Ra 8) - initial/maintained
- Chromaticity tolerance (CDCM) - within steps of MacAdam ellipses - initial/maintained
- Rated life (h) and the related lumen maintenance factor (Lx)
- Failure fraction (By) corresponding to rated life
- Useful Nominal lifetime (Lx.By/hours)
- Rated ambient temperature (ta)
- Luminous Intensity Distribution (cd/1000lm).

(see 1.3.3 for more information on these parameters).

# CHAPTER 1 MEErP Tasks 1 & 0 Report – Scope with quick SCan

## 1.1 Objective

The objective of Task 1 is to define the product category and the system boundaries of the 'playing field' for ecodesign applicable to lighting systems, and to formulate this from a functional, technical and environmental point of view.

Lighting provides a significant contribution to the human experience of buildings and the outdoor environment such as street lighting at night. Buildings, the users within them and, the type of activity they are conducting, influences the lighting requirements that are appropriate for the conditions. The activity that is connected to the so-called "task area" is an especially important driver for lighting requirements. As well as needing to satisfy the basic requirements to enable the fulfilment of tasks, general lighting of buildings provides visibility, orientation and wayfinding. Current research shows that lighting has specific non–visual effects that influence mood, attention and wakefulness. The quality of light & lighting are of primary importance in many applications. Lighting system design is in many applications based on minimum maintained quality parameters as described in European standards such as EN 12464 Lighting of work places, EN 12193 Sports lighting and EN 13201 for Road lighting. Therefore previous EN standards define different sets of lighting requirements related to the activity in the task area, e.g. office work.

Building users require a certain comfort level in the building. This comfort level mainly consists of thermal and visual comfort and depends on the activities that take place in the building. The amount of energy needed to provide this depends on many factors. The energy needed for heating/cooling depends on the building envelope. The glazing surface, its characteristics and orientation, determine the amount of solar gains but also affect the average U-value of the building envelope and the amount of daylight that enters the building. Internal heat gains also need to be taken into account for the energy balance of the building and depend, amongst other factors, on gains from electrical energy conversion to heat within lighting equipment. Artificial lighting, in conjunction with natural daylight through windows, should meet requirements for visual comfort. While lighting systems need to provide a sufficient amount of light, they also need to avoid the risk of glare. Therefore, for example, blinds can be used for glare protection, but also restrict solar gains. This may be a good thing if it prevents overheating and thus reduces cooling demand but could be a negative if it were to reduce solar gains that would otherwise have offset heating demand. Control systems, for heating, cooling, ventilation, artificial lighting and blinds, can help increase the energy efficiency of a building. This study focuses on the lighting system but will also take into account its interaction with other building energy systems and flows.

This is a parallel study to another Ecodesign study on Light Sources[5], this resulted mainly in policy recommendations to increase the initial(@100h) lamp efficacy. In this study we will focus on many other improvement options to lower impact and energy consumptions of installed lighting systems, such as controls, wall reflectance, optics, ..

Visual comfort is that main factor to take into account for outdoor lighting applications, but also light wastage (such as light pollution) has to be avoided. The part of the light that does not illuminate the targeted area is considered to be un-

[5] http://ecodesign-lightsources.eu/

useful and wasted, especially upwards light that causes sky glow and the obtrusive light that bothers people

Task 1 is important as it provides:

- an inventory of what measures already exist in the EU (with possible regulatory failures);
- an analysis of the legislation in EU Member States,;
- an indication –also in view of global competitiveness and hinting at feasible target levels—of what measures have been taken in the rest of the world outside the EU.

The "MEErP Task 0" analysis is included in section 1.6 at the end of this chapter. This is an optional task in addition to task 1 to be used in the case of large or inhomogeneous product groups, where it is recommended to carry out a first product screening considering the environmental impact and potential for improvement of the products as referred to in Article 15 of the Ecodesign Directive. The objective is to re-group or narrow the product scope, as appropriate from an ecodesign point of view, for the subsequent analysis in tasks 1-7."

## 1.2 Summary of Tasks 1 and 0

Note, this text has been written during a preparatory phase of this study and the summary will be updated in the final version taking into account input that might arise from further Tasks and/or relevant updates on standards as they might impact proposals within the future Task 7.

This is a reviewed draft version of Task 1. In a multi stakeholder consultation, a number of groups and experts provided comments on a preliminary draft of this report. The report was then revised, benefiting from stakeholder perspectives and input. All written stakeholder comments and answers are available in a separate Annex to Task 1 that is available on the project website[6]. The views expressed in the report remain those of the authors, and do not necessarily reflect the views of the European Commission or the individuals and organisations that participated in the consultation.

The proposed scope of the study is: the investigation of lighting systems that provide illumination to make objects, persons and scenes visible wherein the system design based on minimum quality parameters as described in European standards such as EN 12464 Lighting of work places and EN 13201 for Road lighting. The primary relevant parameter is: the functional or useful luminous flux per square meter equal to the minimum required maintained average illumination as calculated with secondary performance parameters as defined in standards in 1 hour of operation. Aside from this several other important lighting system parameters are defined and discussed. The text also explains how the lighting system can be decomposed into subsystems such as: installation, luminaire, LED module, LED control gear, etc. which is necessary to help analyse how different aspects of the system contribute to its overall performance and to its Ecodesign impacts.

Non-residential lighting design, as defined in the standards series EN 12464 for indoor lighting and EN 13201 for road lighting, uses the concept of maintained minimum lighting requirements. As a consequence, maintenance schemes and factors such as lumen depreciation need to be taken into account although this adds additional complexity in lighting system design. As mentioned above, this section also explains

6 http://ecodesign-lightingsystems.eu/introduction

how the system can be decomposed into subsystems and introduces the main parameters specified within the European and international standards to do this. This decomposition and the relation of the system's elements to their respective standards on energy efficiency are graphically represented in Figure 1-1, Figure 1-2 and Figure 1-3. It is important to understand this decomposition when reading the various tasks within the preparatory study. Much of these subsystem parameters will be documented and discussed in Task 3 on Users impact and Task 4 on Technology.

For lighting systems there is not a direct PRODCOM category. PRODCOM is not relevant in the context of lighting 'systems', because they are not recognized as unique products and there is also not a direct PRODCOM category for lighting systems. As a consequence of this alternative product categories were defined that are useful for later Tasks 2, 3 and 4.

Setting out the relevant standards, definitions, regulations, voluntary and commercial agreements on EU, MS and 3rd country level are a key aspect of this task report. For the energy performance of lighting systems the standard prEN 15193 plays an important role for indoor lighting, as does prEN 13201-5 for road lighting. These provisions within these draft standards are respected to the extent possible within this study.

As a complementary component of this Task a first screening of design factors was performed to give a provisional indication of the relevant improvement potential, but these figures will be updated in later Tasks.

The first screening in Task 0 showed that savings at system level can be very significant and can reach up to 90% when comparing the worst case implementation permitted according to the existing legislation after 2017 with the best available techniques. Therefore the proposed scope will be investigated and calculated in more detail in later Tasks.

## 1.3 Product/System scope

**Objective:**

According to the MEErP approach the classification and definition of the products within this Task should be based, primarily, on the following categorizations:

- the product categories used in Eurostat's Prodcom database;
- product categories defined within EN- or ISO-standard(s);
- Other 'product'-specific categories (e.g. labelling, sector-specific categories), if not defined by the above.

In principle Prodcom should be the first basis for defining the product categorisation, since Prodcom allows for precise and reliable calculation of trade and sales volumes (Task 2). However for lighting systems this is not evident as they concern installations and do not correspond to the product categories defined by Eurostat, nevertheless in Task 2 we will look at building statistics (permits, floor area) and road statistics from Eurostat and other data sources.

The product categorizations set out above are a starting point for classifying and defining the products and can be completed or refined using other relevant criteria that address: the functionality of the product, its environmental characteristics and the structure of the market where it is placed. In particular, the classification and definition of the products should be linked to the assessment of the primary product performance parameter (the "functional unit") that will be defined in section 1.3.3.1. If necessary, a further segmentation can be applied on the basis of the secondary product performance parameters, defined in section 1.3.3.2. In that case, the segmentation would be based on functional performance characteristics and not on technology.

Where relevant, a description of the energy systems affected by the energy-related products will be included, as this may influence the definition of the proposed product scope.

The resulting 'product' classification and definition should be confirmed by a first screening of the volume of sales and trade, environmental impact and potential for improvement of the products as referred to in Article 15 of the Ecodesign Directive.

It should also be confirmed by a first screening of the volume of sales and trade, environmental impact and potential for improvement of the products as referred to in Article 15 of the Ecodesign Directive.

In this study a lighting 'system' will be considered to be a 'product' for the purposes of further elaboration of the study. Lighting systems are technical systems installed in buildings, roads or other external applications and are usually not considered as single products brought on the market, but rather as a composition of products installed by an installer often in accordance to the design of a lighting designer. The reason for this is now explained. Lighting installations are elements or components of a building and are not currently treated as distinct 'products' in other parts of European legislation. As a consequence, buildings and/or their installed lighting do not presently carry a CE label for the installation. Thus far, none of the EU harmonised Directives have considered whether installers are involved in the "manufacture" or making of the products they install and in consequence there are no CE marking criteria specified under the terms of EC Decision (768/2008/EC) on a common framework for the marketing of products in the EEA. Therefore 'installers' are not presently seen to be 'lighting system manufacturers' in any legal sense and hence have no administrative requirements imposed on them as a result of the provisions in Article R2 or Annex II of Decision (768/2008/EC), which specify the obligations related to technical documentation and conformity assessment. It should also be noted that as buildings and their lighting installations ostensibly cannot be moved or relocated the 'free movement of goods' is also an irrelevant issue in this context. The consequence of this and the potential impact on further policy options will be discussed in Task 7.

### 1.3.1 Definition of the lighting System scope of this study and context

The scope of this study is the lighting system considered as a holistic system including: light source, control gear, luminaires, multiple luminaires in a system, with sensors, controls and installation schemes (Figure 1-1). In this Figure 1-1 each system level element has its own colour code that will be followed in the remainder of this study. The colour coding applied is: Electrical efficiency (dark green), installation (dark blue), luminaire (sky blue), lamp (orange), control system (light green), control gear (red), and design process (yellow). This demarcation is done to help delineate the various aspects of a lighting system and to enable their contribution to the overall eco-efficiency of the system to be analysed and determined. Non-residential lighting as defined in standard series EN 12464 on indoor lighting and EN 13201 on road lighting use the concept of maintained minimum lighting requirements and as a consequence maintenance schemes and factors such as lumen depreciation over life time need to be taken into account. This creates additional complexity in the design of lighting systems. For those who are not familiar with this concept they can consult freely available literature for indoor lighting requirements according to EN 12464[7]. Road lighting EN 13201 uses a similar approach but the precise minimum requirements may have different specifications among the Member States, see TR/EN 13201-1 in section 1.4.2. On road lighting there is also freely available literature explaining how this standard and its approaches are applied[8]. The most relevant performance parameters used in European and international standards are defined in section 1.3.3. They will be further documented and discussed in Task 3 which addresses the Users and Task 4 which concerns Technology. Therefore, for the further reading of the subsequent task reports it is important to understand the decomposition presented in the figures below and all its defined parameters, as it will be followed throughout the entire study.

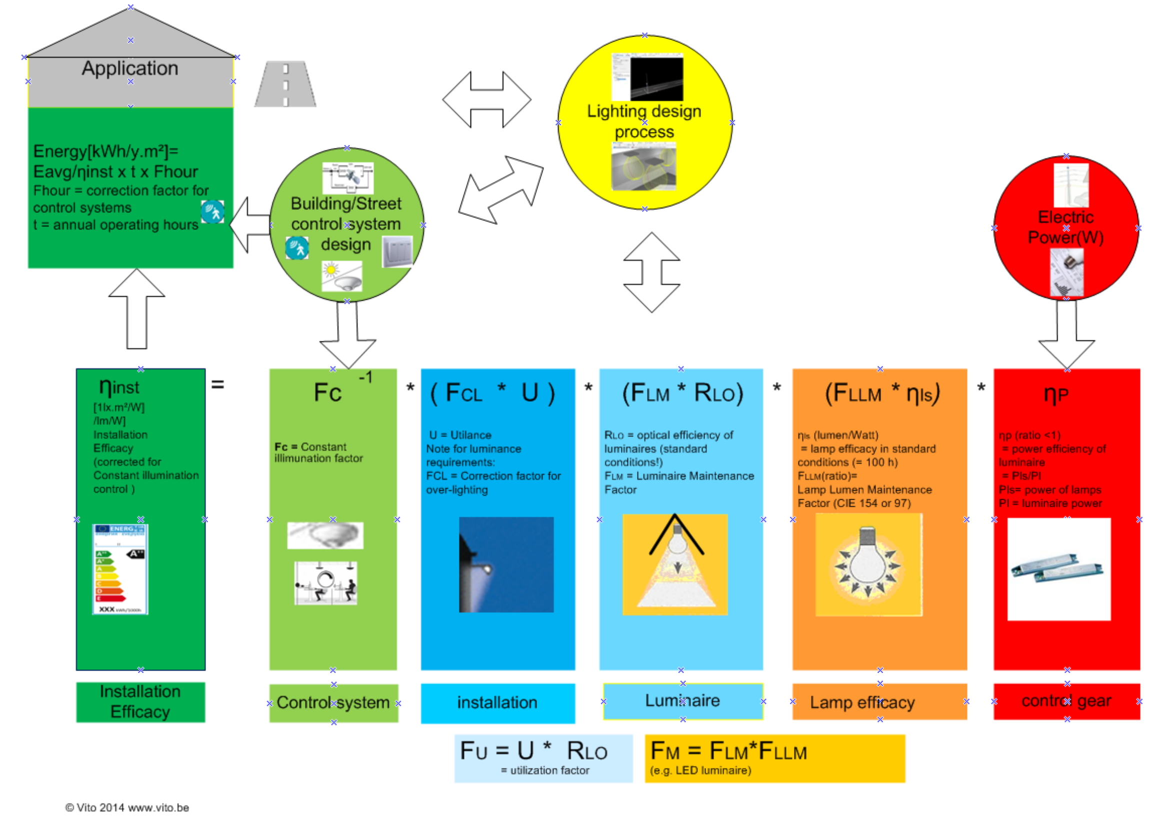


*Figure 1-1: Components of a lighting system and the most relevant performance parameters related to energy efficiency*

The improvement options which can be applied at light source level, such as control gear and lamp efficacy, were already extensively studied in the eco-design study on light sources[16] thus this study will make use of this complementary information but will not reassess it. A new aspect is that the improvement options at the installation level and control systems level will be studied in Task 4 and beyond. In addition, installation energy performance will be calculated according to the new standards EN 15193 and EN 13201-5.

An intention of this study is to examine the application level of lighting. In this context, lighting system means any energy-related device or system of devices used for the production of artificial lighting from the power supply in household lighting or non-domestic lighting. A lighting system can therefore range from simple luminaires to

[7] www.licht.de : Guide to DIN EN 12464-1 Lighting of work places –Part 1: Indoor work places, ISBN: 978-3-926193-89-6
[8] www.licht.de : Guide No. 03, 'Roads, Paths and Squares, ISBN 978-3-926193-93-3

large scale installations with multiple luminaires and intelligent controls such as those used in intelligent street lighting. Lighting systems can be placed on the market either with built-in lamps that are not designed to be changed by the end-user, such as fixed LED modules, or with exchangeable lamps/without lamps. Lighting schemes are plans for a lighting system and allow assessment of the system at the early design stage. 'Smart' lighting systems based on advanced control systems are also considered in this study.

In past Ecodesign preparatory studies of non-residential lighting the primary function was defined as 'provided illuminance in one hour operation', or in particular cases of street lighting the 'provided luminance in one hour operation'. Other secondary functional design parameters are for example glare reduction, uniformity, colour rendering, and colour temperature. In non-residential lighting, system design is often based on minimum performance levels sourced from standards. This results in lighting system design wherein several standards and methods are involved. This is illustrated in Figure 1-2 for public outdoor lighting and in Figure 1-3 for indoor lighting of work places. The standards and their relevant parameters are explained in section 1.4.
For indoor lighting minimum requirements are defined in EN 12464-1 and are mainly based on the following parameters (see also 1.3.3): maintained illuminance (Em), UGR limits for rating glare (UGR), Uniformity (U0) and colour rendering index (Ra). For street lighting similar requirements are defined in EN 13201 standards series.

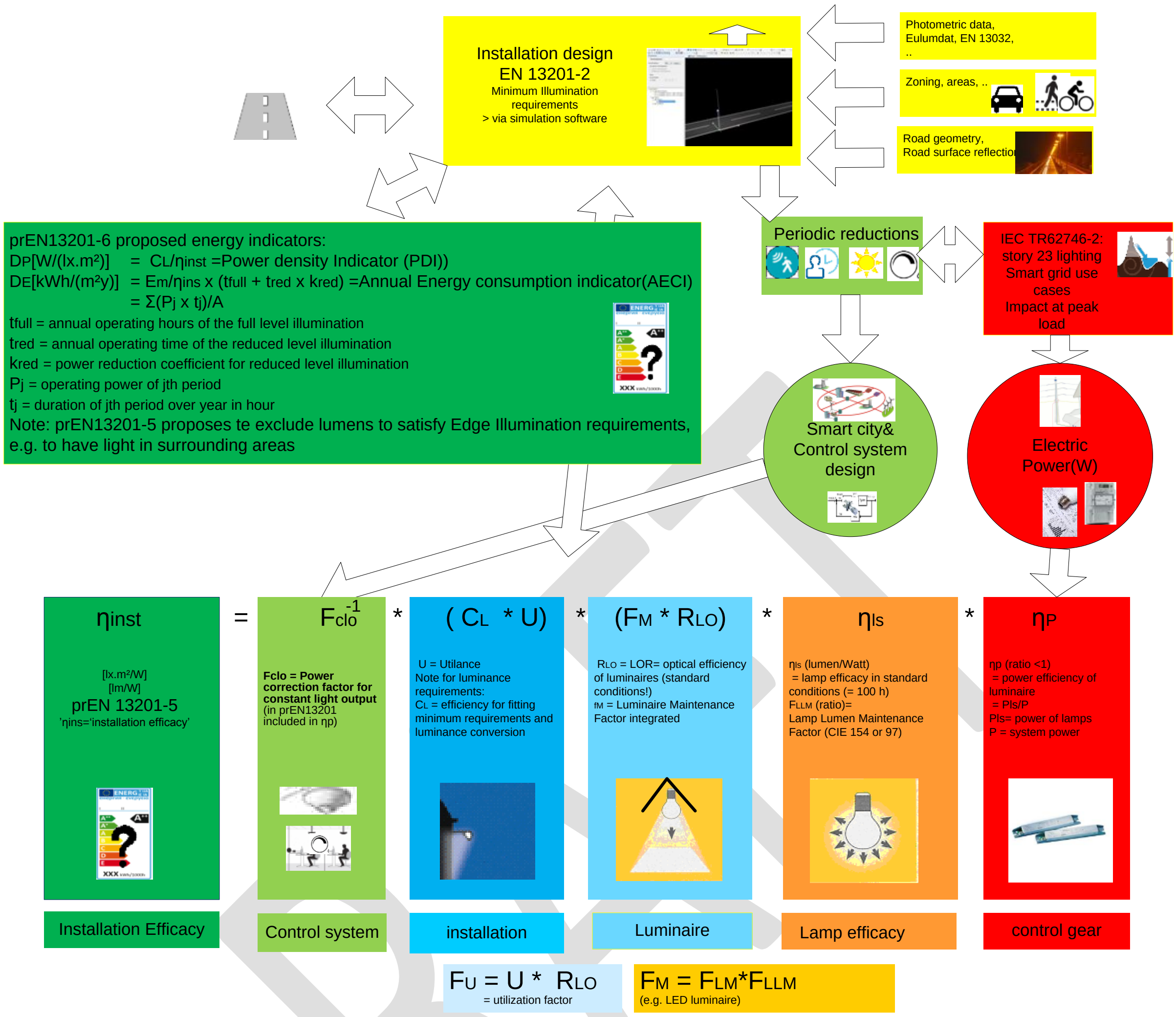


*Figure 1-2: Context of public outdoor lighting systems with related standards and methods*

On the other hand, this approach is not applied in domestic or residential lighting and some other similar application areas. In this case lighting system design is not based on predefined minimum performance standards but is done empirically based on the experience of the designer, installer and/or user, user need, user preference and the overall environmental appearance.

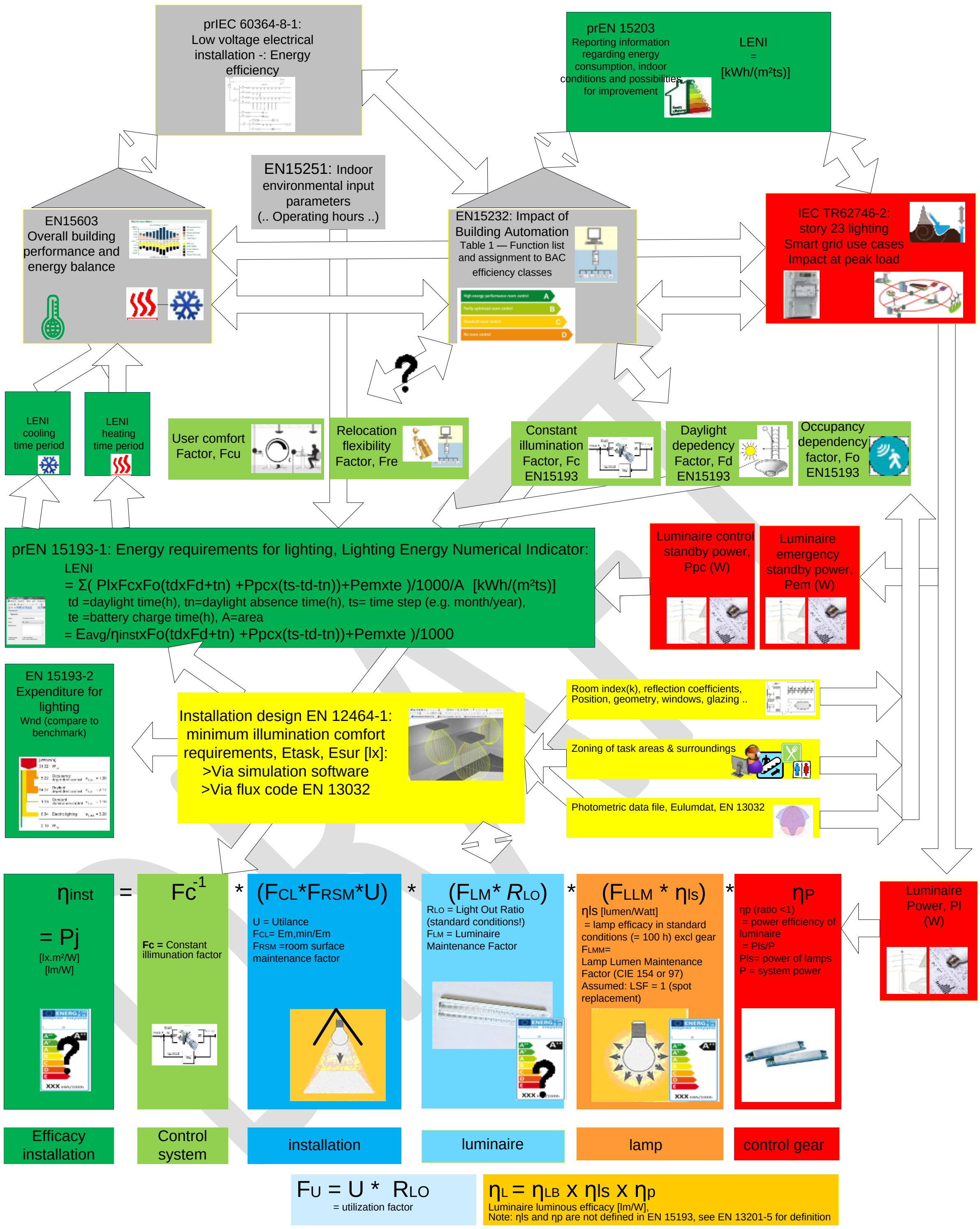


*Figure 1-3: Context of indoor lighting systems for work places with related standards and methods*

**In summary the primary scope of this study is the investigation of *lighting systems that provide illumination to make objects, persons and scenes visible wherein the system design based on minimum quality parameters as described in European standards EN 12464-1 on lighting of indoor work places and EN 13201 for Road lighting.***

In other words, the scope is a lighting system or installation that is designed to fulfil the minimum requirements that are included in standard EN 12464-1 or EN 13201. This includes the design, installation, use and decommissioning of such a system. Such a system can for example include several luminaires and sensors. The focus in this study is on lighting 'systems', therefore light sources and single components such as lamps will not be discussed in detail. These are being addressed in a separate ongoing study concerning light sources and components (Lot 8/9/19 - *Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements*). Some road or building infrastructure components do have an important impact on the performance of a lighting system but are, however, in a strict sense not part of that lighting system itself, for example: occupants, floor, wall, ceiling surface, power cables, control cables, road surface, lighting poles, windows, solar blinds, etc. These parts are often installed for other building functions and/or are connected to the general building technical infrastructure. Cable losses fom lighting circuits were already studied in the 'Preparatory Studies for Product Group in the Ecodesign Working Plan 2012-2014: Lot 8 - Power Cables'[9]. These building parts will be taken into account in this study Task 3 being the system environment of the lighting system, see Task 3.

<u>The following types of lighting system are therefore excluded from the scope:</u>

- Lighting systems designed for other purposes than providing illumination, for example:
  - Lighting systems designed to make themselves visible for purposes of signage or displays (e.g. advertising lights, traffic lights, television sets, tablets, Christmas lighting chains, light art works, light art installations, etc.).
  - Lighting systems designed to make themselves visible for purposes of signage or displays including works of art that are self-illuminating or rely on specific illumination to achieve the artists required outcome are therefore excluded. They are excluded from most tasks of this study because they would lead to an inconsistent study needing separate analysis (sales, energy consumption, life, usage characteristics, and availability of standards, scenario analysis, policy options, and impacts).
    - Emergency lighting installations is also excluded because such equipment is already covered with other regulation, has low operating hours and was therefore excluded[10] from previous eco-design legislation.
    - In residential systems the standards EN 12464 and EN 13201 are not applicable and as a consequence they are excluded.
    - Please note that emergency lighting equipment when integrated with general illumination (e.g. in the UK) is proposed to be within the scope for parts related to general illumination, see also approach in prEN 15193. If it is not integrated it is out of the scope.

[9] http://erp4cables.net/
[10] http://ec.europa.eu/energy/en/topics/energy-efficient-products/lighting

**Rationale and considerations concerning the scope:**
The scope indicated above is a clear definition connected to the well-established standards in the field: EN12464 for indoor lighting and the EN 13201 series for road lighting. Therefore lighting systems can be clearly defined, which is useful for any further legislative purpose, and also their performance parameters can be sourced from standards as will be documented later in section 1.4. In the Task 2 study on markets, the Task 0 study on screening and the Task 4 on technologies the scope may be further reduced depending on which lighting systems are relevant and where technology is available for improvement.

Are installed lighting systems in buildings or in road lighting products covered in the meaning of the Ecodesign of Energy Related Products Directive (2009/125/EC)?

As summarised earlier, the consequence of the scope selected for this lighting system study is that it targets the specification, design and installation of an entire system composed of multiple products such as luminaires, lamps, sensors, etc. This is different from many other preparatory studies carried out to prepare implementing measures under the Ecodesign of Energy Related Products Directive (2009/125/EC), which have tended to be confined to factory finished products.
Up to now no EU harmonised Directive has treated installed lighting systems as specific products by setting marking requirements for them and in consequence installed power circuits are not currently required to carry a CE label, although individual components within them generally are. As a result installed lighting systems are not currently mentioned within the existing product categories of the CE product marking Directive (93/68/EEC). The Ecodesign of Energy Related Products Directive (2009/125/EC) defines an 'Energy-related product' or a 'product' as being 'any good that has an impact on energy consumption during use which is placed on the market and/or put into service, and includes parts intended to be incorporated into energy-related products covered by this Directive which are placed on the market and/or put into service as individual parts for end-users and of which the environmental performance can be assessed independently'. Therefore and as a conclusion nothing has been found to preclude the possibility of considering 'installed lighting systems' as 'products' and installers and designers as their 'manufacturers'. It remains a policy option to be decided by the EC. This issue and potential policy options will be further discussed in Task 7. In the remaining Tasks this study will therefore follow the MEErP methodology, see 0.1, to the extent this is possible. An overview and discussion of related legislation is given in section 1.5 of this Task report.

### 1.3.2 Categorisation of lighting systems

**Objective:**
PRODCOM is not relevant in the context of lighting 'systems', because lighting systems are not recognized as unique products and therefore not included in European product statistics. Therefore, the scope of this investigation will follow the decomposition proposed in the context in Figure 1-1, Figure 1-2 and Figure 1-3 into so-called system levels. Each of the levels will be discussed briefly including the main categories that are defined in European or international standards and/or sector specific methods. The standards are explained later in section 1.4. This categorization based on 'levels' within the system is mainly used for the technical analysis in Task 4 that considers improvement options. The sections hereafter are brief and generic discussion, because in lighting system many potential products and combinations thereof are possible which would lead us to far without contributing to the study.
It is also possible to categorise lighting systems according to the type of task area's defined within the standard EN 12464 on indoor lighting and the EN 13201 standards series. This approach will be briefly introduced and applied in Task 2 concerning

market data and Task 3 concerning user requirements, including for the definition of reference lighting system user applications. This categorisation will be introduced in a separate section and more details described in a later section addressing these standards and in the parts of Tasks 2 and 3 where they are relevant.

### 1.3.2.1 Lighting systems at design and installation level:

The lighting system at the design and installation level is denoted by the dark blue in Figure 1-1.

This lighting system level spans the whole system approach and takes into account:

- the surroundings (building, room, workplace, street, parking place, park etc.)
- the means used to mount or suspend the luminaires (ceiling, wall, pole etc.)
- the lighting calculation in accordance with the appropriate standard including optimisation for energy consumption
- the choice of a lighting management system including sensors, controls and communication network
- the choice of the luminaire including light source, ballast and optic
- the choice of an emergency escape lighting system
- and finally also the installation and commissioning of the whole system.

Depending on the application area lighting systems will be simple, more complicated or very sophisticated. The application areas can be categorized as:

- Indoor residential
- Indoor non-residential, specific lighting requirements are defined in EN 12464 for task areas related to:
    - Education
    - Hotels & restaurants
    - Hospitals and healthcare facilities
    - Retail
    - Offices
    - Sports & recreation
    - Industry
    - Agriculture
    - other
- Outdoor public lighting
    - Road lighting defined as 'Traffic route lighting' where motorized traffic is predominantly motorized, typically associated with class M from prEN 13201-1:2014.
    - Road lighting defined as lighting 'Street lighting' where traffic is significantly mixed or predominantly non-motorized, typically associated with class P from prEN 13201-1:2014.
    - Traffic signals
    - Tunnel lighting (which is not part of EN 13201, see section1.4.2)
    - Monument lighting
    - Other
- Outdoor non-public lighting
    - Service & recreational sector
    - Industry, with lighting requirements as defined in EN 12464-2
    - Households
    - Other

Lighting standards do not exist for all categories of application area.

The European standards EN 12464-1: 'Light and Lighting – Lighting of indoor workplaces' and EN 12464-2: 'Light and lighting – Lighting of outdoor workplaces' impose minimum lighting and comfort levels for different task areas. They are applicable in offices, industry halls, education buildings, outdoor workplaces, hospitals and outdoor park places.

Only EN 50172: 'Emergency escape lighting systems' is applicable for use in all indoor lighting area categories. EN 50172 does not cover private residential premises but its provisions are applicable to common access routes within multi-storey dwellings.
For street lighting, the performance parameters can be found in EN 13201-2: 'Road lighting - Part 2: Performance requirements.'
EN 12193: 'Light and lighting - Sports lighting' does not only propose minimum levels for lighting and comfort but also maximum values to minimise obtrusive light.
EN 13201 series covers road lighting but does not include tunnels. Tunnels are part of national standards.

#### *1.3.2.2 Luminaires as part of the system*

The luminaire level of the lighting system is denoted by light blue in Figure 1-1.
A "luminaire" is defined in EN 12655 as an "apparatus which distributes, filters or transforms the light transmitted from one or more light sources. A luminaire with integral non-replaceable lamps is regarded as a luminaire, except that the tests are not applied to the integral lamp or integral self-ballasted lamp.
A luminaire can contain several parts wherein (see also section 0.4), for example:

- A 'LED Lamp' meaning a technology LED light source incorporating one or more LED package(s) or LED module(s) and provided with one or more cap(s) as defined in CIE DIS 024/E:2015. Furthermore EN 62504:2014 requires that 'A LED lamp is designed so that it can be replaced by an ordinary person as defined in IEC 600500-826, 826.18.03';
- A 'Ballast' meaning (EN a device connected between the supply and one or more discharge lamps which serves mainly to limit the current of the lamp(s) to the required value;
- 'LED control gear' meaning a unit inserted between the electrical supply system and one or more LED package(s) or LED module(s) which serves to supply the LED package(s) or LED module(s) with its (their) rated voltage or rated current;

Light sources and control gear are being analysed as a product group in a separate Ecodesign study (Lot 8/9/19) as explained previously. Red is the colour coding indicating elements applying to control gear.

#### *1.3.2.3 Lighting control system*

The lighting control system level is denoted by light green in Figure 1-1.

Lighting controls are available for almost all lighting applications and some examples are listed below.

##### *1.3.2.3.1 For indoor lighting (offices, indoor work places, sports halls etc.) some control systems are:*

**Daylight dependent lighting control**

- It regulates and shuts down the artificial light output in accordance with the level of natural light.

- It results in energy savings when daylight is available.
- In some cases it can control the light individually with imperceptible automatic dimming
- It uses daylight responsive sensors, i.e. clicked onto the lamp, integrated into the housing, etc.
- Most often the daylight sensor will control a standard dimming electronic ballast or LED-driver, typically the daylight sensor controls an 1-10V analogue input or a DALI-digital input of the control gear.
- Sometimes the daylight sensor can work with proprietary control gear using a digital signal, e.g. wireless Zigbee[11].

**Movement dependent lighting control**

- uses a sensor to switch the luminaire on or off depending on whether any people are present in the room.

**For previous systems with automatic presence and/or absence detection the following four situations are valid according to EN 15193**

- 'Auto On / Dimmed': the control system automatically switches the luminaire(s) on whenever there is presence in the illuminated area, and automatically switches them to a state with reduced light output (of no more than 20 % of the normal 'on state') no later than 15 minutes after the last presence in the illuminated area. In addition, no later than 15 minutes after the last presence in the room as a whole is detected, the luminaire(s) are automatically and fully switched off.
- 'Auto On / Auto Off': the control system automatically switches the luminaire(s) on whenever there is presence in the illuminated area, and automatically switches them entirely off no later than 15 minutes after the last presence is detected in the illuminated area.
- 'Manual On / Dimmed': the luminaire(s) can only be switched on by means of a manual switch in (or very close to) the area illuminated by the luminaire(s), and, if not switched off manually, is/are automatically switched to a state with reduced light output (of no more than 20 % of the normal 'on state') by the automatic control system no later than 15 minutes after the last presence in the illuminated area. In addition, no later than 15 minutes after the last presence in the room as a whole is detected, the luminaire(s) are automatically and fully switched off.
- 'Manual On / Auto Off': the luminaire(s) can only be switched on by means of a manual switch in (or very close to) the area illuminated by the luminaire(s), and, if not switched off manually, is automatically and entirely switched off by the automatic control system no later than 15 minutes after the last presence is detected in the illuminated area.

**Users can also manually perform presence detection with simple switches and EN 15193 defined therefore the following two situations**

- manual on/ Auto Off switch.
- manual On/ Off Switch + additional automatic sweeping extinction signal.

Note: the impact in EN 15193 will depend on the control area such that often the smaller the area the more energy savings are achieved.

**The different types of daylight-responsive control systems defined in EN 15193 are:**

- “Manual control” (Type I), means the users controls the on:off switch.

[11] http://www.zigbee.org/

- "Automatic On/off"(Type II), means the electric lighting is automatically switched off when the maintained illuminance is achieved by daylight at the point where the illuminance is measured. The electric lighting is switched on again automatically when the maintained illuminance is no longer achieved by daylight.
- "On/off in stages" (Type III), means the electric lighting is switched off in stages until the maintained illuminance is achieved by daylight at the point where the illuminance is measured. The electric lighting is switched on again automatically in stages when the maintained illuminance is no longer achieved by daylight.
- "Daylight responsive off" (Type IV), means the electric lighting is switched off when the maintained illuminance is achieved by daylight at the point where the illuminance is measured. The electric lighting has to be turned on again manually.
- "Stand-by losses, switch-on, dimmed" (Type V), means the electric lighting is dimmed to the lowest level during usage periods (periods with adequate daylight) without being switched off (i.e. it uses electrical power ("stand-by losses")). The electric lighting system is turned on again automatically.
- "No stand-by losses, switch-on, dimmed" (Type VI), means the electric lighting is switched off and turned on again ("dimmed, no stand-by losses, switch-on"). The electric lighting is dimmed to the lowest level during usage periods (periods with adequate daylight) and switched off (i.e. no electrical power is used). The electric lighting system is turned on again automatically.
- "Stand-by losses, no switch-on, dimmed" (Type VI), means as system V, except that the electric lighting system is not turned on again automatically.
- "No stand-by losses, no switch-on, dimmed" (Type VII), means as system VI, except that the electric lighting system is not turned on again automatically.

**Constant illumination control (EN 15193 and/or EN 13201-5)**

- A sensor measures the real illumination on the task area and fits it to the required minimum value (EN 15103).
- This allows for illumination level compensation to occur for changes in the lumen maintenance of the light source, luminaire optics pollution, line voltage changes and reflections from the environment on the illumination level.
- A constant illumination level also adapts to the levels of daylight by dimming or switching off the lighting when sufficient daylight is available.
- Constant illumination control can also allow fine tuning to the exact required minimum illuminances in cases where over illumination has resulted from the selection of luminaires with higher lumen outputs compared to the minimum required. Because constant illumination controls monitor the light on the task they cannot differentiate between the source of the light, e.g. artificial or natural light.
- Such control is also defined in EN 15193 as "illuminance control". Such schemes are known as "controlled constant illuminance" schemes for installations where a dimmable lighting system is provided and it is possible to automatically control and reduce the initial luminaire output to just provide the required maintained illuminance. Therefore EN 15193 also defines the constant illumination factor (Fc).

- For road lighting a similar control system is defined in EN 13201-5 as 'constant light output CLO (of a road lighting installation)' for 'regulation of the road lighting installation aiming at providing a constant light output from the light sources'.

**Combined systems**

- Daylight and movement sensors can be combined in one system.
- These multi-sensors are very suitable for movement detection in open plan or group offices, possibly in combination with a daylight linking system. In these applications people usually prefer that the light is not switched off but only dimmed in empty rooms. The office is still bright enough for the users sitting elsewhere. The lights are only switched off when the last person has left the office.
- This system is also very useful in other indoor lighting systems e.g. in sports halls.

**Simple local lighting control for dimming or colour control**

- Daylight and movement sensors are combined in one system.
- The lighting can be tailored to personal needs via a manual control, e.g. with dimmers using push-buttons, rotary switch or any other personal user interface such as smart phone.

**Dynamic lighting**

Dynamic lighting is the application of dynamics in the intensity, colour and distribution of (artificial) light. Recent scientific research has proved that light dynamics have an important biological effect and this forms the basis of new applications such as:

- improving the health of people who have little or no daylight at their workplace;
- medical applications, e.g. synchronising the biological clock;
- creating stimulating effects by varying light colours.

Luminaires for dynamic light can vary the intensity, colour and distribution of light. That is why they are fitted with several lamps of different colours and connected to a digital switch start control gear (DALI).

**Building management system**

Light and energy controls are integrated at the building level via building management systems.
An example is a system that can simultaneously apply six different energy management strategies in order to save as much power in a building as possible, comprising:

- intelligent time control
- daylight dependent system
- adaptation to the task environment
- movement detection
- individual control
- limitation of the peak output.

**Fixed dimming**

Most lamp types, especially LEDs, lose efficacy over time and dimming systems can compensate for this. Dimming also allows the illumination level to be fine-tuned exactly to the minimum required, e.g. to compensate for cases when the exact lamp wattage required was unavailable (e.g. 60 W= 0.85 * 70W).

#### 1.3.2.3.2 For outdoor lighting (street lighting, outdoor work places, outdoor sports fields etc.)

**Simple daylight and time responsive on/off switching system**
In this system a photocell, that measures daylight levels, is combined with an internal astronomical clock and comprises:

- a photocell for daylight responsive switching per luminaire or series of luminaires.
- an embedded astronomical clock to switch off the lamp in a low traffic night time period, e.g. from midnight until 6 AM. This astronomical clock is adjusted based on measurements of sunset and sundown. Such a system can detect photocell failures and continue to run on the internal clock when a failure is detected.
- optionally, a communication network (powerline or wireless) can be installed, primarily for maintenance functions to detect lamp malfunctioning or to change the night time switching schemes (e.g. in weekend regime with no switch off after midnight).

**Management system with dimming**
Street lighting is designed to meet the requirements for a road category as defined in the standards depending on traffic density. But this density can decrease during night time and road categorization can change. So dimming based on a nightly time schedule can be installed. Moreover street lights, especially LEDs, lose efficacy over time and dimming systems can compensate for this. Dimming allows also to fine-tune the illumination level exactly to the minimum required, e.g. to compensate when the exact lamp required wattage was unavailable (e.g. 60 W= 0.85 * 70W).

**Management system with dimming and presence detection**
This system has additional sensors that react on the presence of persons or vehicles to dim or switch on or off parts of the installation.

**Management system with dimming, presence detection and speed detection**
In an installation that is dimmed or switched off, speed detection could be used to dim up or down the installation pole per pole to anticipate the road lighting level for a vehicle that drives on that road.

**Constant illumination control (EN 15193 and/or EN 13201-5)**
(see indoor lighting in 1.3.2.3.1)

Note: Every application (offices, hallways, warehouses, streets, etc.) demands a specific light control strategy. This is possible per luminaire or alternatively sensors can be integrated in a master-slave mode and used to control luminaires as a group.

### 1.3.2.4 Lighting system design and calculation software

The lighting system design level is denoted by the yellow colour in Figure 1-1.

Lighting calculation software depends on three important components to produce accurate calculations: the skill of the designer with awareness on standard requirements (and procedures), the selected light sources, and the surfaces within the model.

The selected light sources are characterized by their photometric data. For the presentation of this data, different file formats are used of which a selection of open source file standards are as follows:

**EULUMDAT (frequently used)** is also a data file format used for specification of photometric data from light sources such as lamps and luminaries. The file extension is .ldt. The format was proposed by Axel Stockmar (Light Consult Inc., Berlin) in 1990. The format is an equivalent to the CEN file format.

**IES file format (frequently used)** was developed by the Illuminating Engineering Society of North America (IES) especially for the Electronic Transfer of Photometric Data. All ANSI/IESNA LM-63-2002 filenames end with the file extension .ies or .IES.

**CIBSE file format** was developed by the British Chartered Institution of Building Service Engineers (CIBSE) and is the most commonly used format in the UK.

**CEN file format (never widely adopted)** is the format as specified in the European standard EN 13032-1 (2004) : 'Light and lighting — Measurement and presentation of photometric data of lamps and luminaires — Part 1: Measurement and file format.' Even 10 years after the adoption of this standard, many manufacturers still use other file formats for specifying their lamps or luminaires.

**XML (OXL) format (used in Litestar 4D)** is a relative new public open file format[12] and follows with the modern technology of XML type[13] files which are today widely used in many other applications.

All available lighting software options use one of two methods of calculation: radiosity or raytracing. To better understand how lighting software accurately calculates lighting levels, radiosity and raytracing must be differentiated.

Radiosity Vs. Raytracing[14]

Radiosity is a calculation method that divides each surface into small pieces, called patches. Each patch is calculated individually for the amount of light that enters or leaves that surface. The program then solves the system of equations in the model by determining the quantity of light on each patch as a result of the total sum of all the patches. This method works well for all matte model surfaces since radiosity is based on Lambertian reflectance calculations. Lambertian reflectance refers to surfaces that have reflected light scattered in such a way that the apparent brightness of the surface is the same regardless of the observer's angle of view. Because of the surface dependency of the calculation, the radiosity method can calculate a model once and produce any desired view. A disadvantage to the radiosity method is that it applies to matte and diffuse surfaces only, so contributions from translucent, transparent, and specular (shiny) surfaces are not included in the calculation.

Raytracing, on the other hand, is a point-specific lighting calculation process. Calculation rays are sent outward from a particular viewpoint and the program follows each ray as it hits and reflects off different surfaces and divides into more rays. This method works for all object types including transparent, translucent, and specular surfaces. Raytracing creates beautiful renderings and presentation-quality images by visually representing light on all surfaces, including the sparkle and highlights on specular materials. Unlike radiosity, raytracing is view dependent, meaning renderings

[12] http://www.oxytech.it/Files/Doc/Manuals/LTS4D_OXL-UK.pdf
[13] http://www.w3.org/TR/REC-xml/
[14] http://www.archlighting.com/find-articles.aspx?byline=Jen%20Bickford

must be recalculated from each new angle. Additionally, raytracing can be a slow process, especially if the model contains a large quantity of surfaces.
All lighting software uses one or both of these two options to calculate the illuminance and luminance of surfaces and also provisions to export lighting calculation data.

The most commonly used programmes, free of charge, in Europe are DIALux and RELUX.

- DIALux:
  created in 1994, is a free of charge lighting calculation software. A group of more than 90 international luminaire manufacturers funded the development of DIALux and pay to have their luminaires included with the software package. Updated and maintained by an independent company, DIAL GmbH, DIALux is frequently modified and refined to the requirements of designers. Because the software includes so many different manufacturer fixture libraries, the program retains a type of neutrality. The current release can be downloaded at dialux.com and is available in 26 languages. It is widely used in Europe. Dialux already calculate lighting energy consumption according to EN 15193, but not in interaction with the other energy consuming equipment within the building.
- RELUX:
  is also free of charge lighting calculation software with a large amount of current product data from luminaire, lamp and sensor manufacturers. It also offers sophisticated program add-ons for the professional tasks involved in lighting planning; these are not free of charge.
- LITESTAR 4D:
  This Italian software from OxyTech is not free of charge, is mainly used in Italy and has also an extended library of luminaires, and now comes with OXL (xml) file format.

Also many luminaire manufacturers have their own lighting calculation tools but only for their own luminaires.

As all the preceding programs use a library of luminaires, it is not easy to calculate luminaires that are not represented in their libraries. An exception to this rule is the street lighting calculation software Ulysse, developed by Schréder. This user-friendly software can calculate the necessary luminance and illuminance levels as well as several other parameters in order to provide the optimum solution for various lighting applications. It also allows the introduction of other luminaires and can use different file formats for luminaire data such as EULUMDAT, IES, CIBSE and CEN. So this software minimises barriers due to file format and optimisation needs.

A guideline is available to evaluate the accuracy of lighting design software, see CIE 171 discussed in section 1.4.2.

**Three main gaps** can be observed for lighting calculation software:

- At the moment, different file formats for luminaire data are used, but most of the programmes cannot calculate with all formats.
- Many programmes only calculate an installation without optimising to the most energy efficient solution.
- Although universities in Germany have done research on calculation software and CIE 171 provides a guideline on the method for indoor lighting, there are few calculation programmes that are certified by an independent authority.

There is also a software program called DAYSIM. This is a RADIANCE-based daylighting analysis software that models the annual amount of daylight in and around

buildings. DAYSIM allows users to model dynamic facades systems ranging from standard venetian blinds to state-of-the-art light redirecting elements, switchable glazing and combinations thereof. Users may further specify complex electric lighting systems and controls including manual light switches, occupancy sensors and photocell controlled dimming.
Simulation outputs range from climate-based daylighting metrics such as daylight autonomy and useful daylight illuminance to annual glare and electric lighting energy use. DAYSIM also generates hourly schedules for occupancy, electric lighting loads and shading device status which can be directly coupled with thermal simulation engines such as EnergyPlus, eQuest and TRNSYS.

#### 1.3.2.5 Lighting control communication systems

This is a relative new area wherein also often new technologies and standards are introduced to the market.

Examples of wired lighting communication systems are:

- DALI[15] (following standard IEC 62386)
- DMX512: Is a method for linking controllers (such as a lighting console) to dimmers and special effects devices. DMX has also expanded to uses in non-theatrical interior and architectural lighting.

Examples of a wireless lighting communication system are:

- ZigBee Light Link Standard.
- Bluetooth operated smart lamps.

An example of a power line lighting control system is:

- LEDOTRON: is a digital dimming method using the powerline for data transmission and uses therefore the existing wiring.

#### 1.3.2.6 Retrofittable components for luminaires

See preparatory study on light sources[16] and the Omnibus review.

#### 1.3.2.7 Summary of proposed lighting system categories based on technology levels within a lighting system

Lighting system categories have been proposed that follow the decomposition the system into 'system design or installation level' itself and its subsystems 'luminaires', 'control system', 'lighting system design software' and 'Lighting Control Communication Systems'. This follows the structure introduced in the previous section 1.3.1 and can be aligned with the parameters and approaches defined in existing standards as will be illustrated in the following sections.

#### 1.3.2.8 Categorization of lighting systems according to EN 12464 Task Area's or EN 13201 Road Classes

The standard EN 12464 defines the zoning of work places and their illumination requirements. This comprises the following areas:

- Task area as the area within which the visual task is carried out.
- The area surrounding the task area within the visual field

[15] http://www.dali-ag.org/discover-dali/dali-standard.html
[16] http://ecodesign-lightsources.eu/

- The area adjacent to the immediate surroundings.

For each type of area specific minimum requirements are formulated depending on the application, see Figure 1-4. The technical parameters within these are explained in section 1.3.3.2 and the standard is discussed in section 1.4.2.
Hence it is possible to categorise lighting systems as combinations of the Task Area's defined in EN 12464. This might be useful in Tasks 2 and 3. Such specific Task Areas can be linked to building statistics, for example office buildings.

| Ref. no. | Type of area, task or activity | $\bar{E}_m$ lx | $UGR_L$ – | $U_o$ – | $R_a$ – | Specific requirements |
|---|---|---|---|---|---|---|
| 5.26.1 | Filing, copying, etc. | 300 | 19 | 0,40 | 80 | |
| 5.26.2 | Writing, typing, reading, data processing | 500 | 19 | 0,60 | 80 | DSE-work, see 4.9. |
| 5.26.3 | Technical drawing | 750 | 16 | 0,70 | 80 | |
| 5.26.4 | CAD work stations | 500 | 19 | 0,60 | 80 | DSE-work, see 4.9. |
| 5.26.5 | Conference and meeting rooms | 500 | 19 | 0,60 | 80 | Lighting should be controllable. |
| 5.26.6 | Reception desk | 300 | 22 | 0,60 | 80 | |
| 5.26.7 | Archives | 200 | 25 | 0,40 | 80 | |

*Figure 1-4 Specific minimum lighting requirements for Offices in EN 12464.*

The same can be done for road or street lighting. Eurostat provides data on road categories and they can be linked to typical lighting requirements formulated in EN 13201-2.
Eurostat also provides road transport infrastructure statistics, which contain the following road categories:

- Motorways, which belong typically to EN 13201-2(2016) or CIE 115 'road class M' (Motorized traffic).
- E-roads: which also belong typically to EN 13201-2(2016) or CIE 115 'road class M' (Motorized traffic).
- State, province and communal roads, which belong typically to EN 13201-2(2016) or CIE 115 'road class C' (Conflict area traffic).

In each EN 13201-2(2016) road class (M, C, P), e.g. M, several subclasses exists, e.g. M1 to M6 with M6 having the highest light levels.

- Other roads inside or outside built up areas: which also belong typically to EN 13201-2(2016) oe CIE 115 'road class P' (Pedestrian Area traffic).

For more information on the EN13201-2(2016) standard series see section 1.4.2. Such a subdivision can be useful in in Tasks 2 and 3 to analyse market data and to define typical applications.

### 1.3.3 Definition of the performance parameters for lighting systems

#### *1.3.3.1 Primary performance parameter (functional unit)*

**Objective:**
Knowing what the functional lighting system is as defined before, we will now further explain what is considered to be the "functional unit" for lighting systems, which form parts of the technical installation of buildings or roads.

In standard 14040 on life cycle assessment (LCA) the functional unit is defined as "the quantified performance of a product system for use as a reference unit in life cycle assessment study". The primary purpose of the functional unit is to provide a calculation reference to which environmental impacts (such as energy use), costs, etc. can be related and to allow for comparison between functionally equal lighting systems. Further product segmentations, based on so-called secondary parameters, will be introduced in this study in order to allow appropriate equal comparison.

Proposed definition:
Table 1-1 gives a comparison of the different functional units that were used in the preparatory studies on lighting: lot 8 (office), lot 9 (street), lot 19 (residential).

*Table 1-1: Comparison of different functional units used in the preparatory studies on lighting*

| Lighting study | Product boundary | System | Functional unit | Functional lumen |
|---|---|---|---|---|
| Domestic (lot 19) Part 1 | Lamp (NDLS) | Luminaire, room, wiring | **Lumen*h** (luminous flux in one hour) | All lumen (4π sr) |
| Domestic (lot 19) Part 2 | Lamp (DLS) | Luminaire, room, wiring | **Lumen*h** (luminous flux in one hour) | Directed lumen (0.59π s, π sr) |
| Tertiary (lot 8&9) Street&office | Luminaire+lamp | Room, task area, wiring | **Lumen*h/m² = lx*h** (illuminance in one hour) | Lumen in task area |

In the studies on non-residential lighting, the chosen functional unit was the 'provided maintained illuminance (Em[lx]) in one hour of operation' or in particular cases of street lighting the 'provided luminance in one hour of operation'. This matched well with the practice of professional lighting design found in those sectors. In professional design, those units are primary parameters (besides glare reduction, uniformity, etc.). In street lighting, when luminance was used instead of illuminance, the functional lumens need to be multiplied with a reflection coefficient. This approach and many of the conclusions of those studies can be used in other non-residential lighting sectors and/or applications. It is important to note that 'maintained illuminance' is used because this is applied in the non-residential lighting standards EN 12464 and EN 13201. As a consequence maintenance schemes and parameters such as lumen depreciation over life time are taken into account. Those parameters therefore belong to the so-called secondary system performance parameters discussed in section 1.3.3.2.

In residential lighting the function of lighting is often different and another functional unit was selected. The function is often to create so-called 'ambient lighting'. In the case of ambient lighting, the focus is not to provide illumination in a task area but to provide the proper luminance of a variety of elements in the interior including the luminaire itself. The luminance then depends on the reflection properties of the objects. In ambient interior lighting, due to the very different nature of interior objects and their orientation, quantification of the reflection of the interior is difficult and no luminance calculations are done by the owner or designer. Also for these applications the number of tasks, their time duration and their area can vary strongly which would make a meaningful quantification of illumination requirements difficult for a so-called task area. Finally, in residential applications part of the light generated within a luminaire is often used to provide luminance on the decorative ornaments of the luminaire itself and the usefulness and/or function is hard to quantify.

**The relevant primary parameter is:**
**The functional or useful luminous flux (Φ [lm]) per square meter(Ai[m²]) equal to the minimum required maintained average illumination (Em,min [lx]) as calculated with secondary performance parameters as defined in standards in 1 hour of operation [1 lx/h = 1 lm/(m².h)]**

<u>Notes:</u>

- The unit 1 lumen per square meter is equivalent to 1 lux, hence illuminance (Em);
- **Em, min** in indoor lighting is the minimum average maintained illuminance (Em) specified for the task area in EN 12464-1.
- For road lighting where luminance(Lm) is used instead of illuminance (Em), the following conversion formula can be used(see also EN 13201-5), assuming a reference asphalt reflection coefficient:

$$Em,min = Lm,min/0.07$$

- For road lighting where hemispherical illuminance(Ehs) is used instead of illuminance(E), the following conversion formula can be used(see also in EN 13201-5):

$$Em,min = Lm,min/0.65$$

where:

Em,min is the minimum average maintained illuminance of the functional unit
Lm,min is the minimum average maintained luminance (cd/m²)
Ehs, min is the minimum average maintained hemispherical illuminance (lx)

#### 1.3.3.2 The secondary performance parameters used to calculate the primary performance parameter are (see EN 12665)[17]

**Objective:**
This section lists the secondary parameters are listed that are sourced from the relevant European and international standards. Details from the standards and potential gaps are discussed in section 1.4. The decomposition proposed in Figure 1-1 in section 1.3.1 is abided by and this structure or 'categorization' will also be applied in later Tasks, e.g. in Task 3 on Users and Task 4 on Technology. Those tasks will also give more background and data compared to the simple listing presented below. At this stage in Task 1 it is important to conclude/evaluate whether all necessary parameters required to define the performance of the lighting system can or cannot be sourced from available standards.

The principal design parameters which shall be considered when determining the lighting requirements are:

[17] The definitions of 'nominal' and 'rated' value are not mentioned in EN 12665(2002), but in several other standards such as EN 60081 and EN 50294. A 'rated value' is the value of a quantity used for specification purposes, established for a specified set of operating conditions of a product. Unless stated otherwise, all requirements are set in rated values; a 'nominal value' is the value of a quantity used to designate and identify a product

- **Maintained illuminance, Em [1 lx = 1 lm/m²]**
  value below which the average illuminance on the specified area should not fall, for example as specified in EN 12464 or EN 13201;
- **Maintained luminance, Lm [1 Cd/m²]**
  Is the minimum average luminance or value below which the average luminance on the specified area should not fall, for example as specified in EN 13201;
- **Illuminance uniformity, U0**
  Ratio of minimum illuminance to average illuminance on a surface, for example as specified in EN 12464 or 13201.
- **Unified Glare Rating, UGR**
  The degree of discomfort glare caused by a lighting system according to standard CIE 190.
- **Threshold Increment, TI**
  The measure of disability glare expressed as the percentage increase in contrast required between an object and its background for it to be seen equally well with a source of glare present (standard CIE 150).
- **The colour related parameters are discussed with the light sources**
- **Others can be defined in task 3.**

Important energy performance parameters are:

- **Lighting Energy Numeric Indicator, LENI [kWh/m²year]**
  The estimated annual power consumption of the indoor lighting system according to EN 15193.
- **Annual Energy Consumption Indicator, AECI or $P_E$ [kWh/m²year]**
  The estimated annual power consumption of the road lighting system according to prEN 13201-5.
- **Installation luminous efficacy , $\eta_{inst}$ [lm/W]**
  The quotient of the functional lumen needed to satisfy the minimum illumination requirements versus the input power(Annex B, prEN 13201-5, as defined for this study).
- **Lighting power density indictor, PDI or $D_P$[W/(lx.m²) = W/lm]**
  value of the system power divided by the value of the product of the surface area to be lit and the calculated maintained average illuminance value on this area according to EN 13201-3 (unit: $W.lx^{-1}.m^{2}$ or W/lm). Note this is and the reverse value of installation luminous efficacy (Dp = =$C_L/\eta_{inst}$).

Important secondary control gear parameters are:

- **Maximum luminaire power, $P_I$ [W]**
  The luminaire power Pi shall be the declared circuit power of the luminaire when operating at maximum power. The value of Pi shall include the power supplied to operate all lamp(s), ballast(s) and other component(s) when operating at maximum power(EN 15193);
- **Rated lamp power, $P_r$ [W]**
  Quantity value of the power consumed by the lamp for specified operating conditions. The value and conditions are specified in the relevant standard;
- **Nominal lamp power, $W_{lamp}$ [W]**
  Approximate wattage used to designate or identify the lamp;

- **Power efficiency of luminaires $\eta_p$**
  ratio between power of lamp(s) and the maximum luminaire power (Annex B, prEN13201-5);
- **Ballast maintenance factor, $F_{BM}$ (defined in previous preparatory studies)**
  the ratio of the worst ballast efficiency at a given time in its life to the initial ballast efficiency in standard conditions;
- **Ballast Reliabilty, BR**
  The percentage of failed ballast per 1000h @70°C operating temperature (defined in lot 8&9). Note: for LED luminaires new but similar failure parameters are defined with luminaires;
- **Ballast gain factor, BGF (defined in previous preparatory studies)**
  Because the energy savings by dimming are related to a feature in the ballast type, a correction factor 'Ballast Gain Factor' can be introduced.

As $P_{dim} = P_{normal} / F_{BG}$

and $P_{dim} < P_{normal}$

it is obvious that $F_{BG} > 1$ for dimmable ballasts. For non-dimmable ballasts $F_{BG} = 1$.

Important lamp/light source parameters are:

- **Luminous efficacy of a light source used in the installation, $\eta_{ls}$ [lm/W]**
  Quotient luminous flux emitted by the power consumed by the light source excluding energy consumed by the gear and any other electrical devices(Annex B, prEN 13201-5);
- **Rated luminous flux, Φr [lm]**
  value of the initial luminous flux of a given type of lamp declared by the manufacturer or the responsible vendor, the lamp being operated under specified conditions;
- **Nominal luminous flux, Φn [lm]**
  A suitable approximate quantity value of the initial luminous flux of the lamp,
- **Lamp Lumen Maintenance Factor, $F_{LLM}$**
  Ratio of the luminous flux emitted by the lamp at a given time in its life to the initial luminous flux;
- **LED module rated life, Lx** (IEC 62717)
  length of time during which a LED module provides more than claimed percentage x of the initial luminous flux, under standard conditions;
- **Lamp Survival Factor, $F_{LS}$**
  Fraction of the total number of lamps which continue to operate at a given time under defined conditions and switching frequency;
- **LED module failure fraction, Fy** (IEC 62717)
  percentage y of a number of LED modules of the same type that at their rated life designates the percentage (fraction) of failures;
- **CIE general colour rendering index, CRI [$R_a$]**
  Mean of the CIE special colour rendering indices for a specific set of a test colour samples. 'a' indicates the number of colour samples the colour rendering index is based on: e.g. $R_8$ or $R_{20}$.);
- **Chromaticity coordinates**
  Coordinates which characterise a colour stimulus (e.g. a lamp) by a

ratio of each set of tristimulus values[18] to their sum.
The CIE defines different colour spaces with its own coordinates, for light sources the most common system is 'CIE xy' also known as 'CIE 1931 colour space'. The gamut of all visible chromaticities on the CIE plot is tongue-shaped or horseshoe-shaped shown in colour in Figure 1-5. Light with a flat energy spectrum (white) corresponds to the point (x,y) = (0.33 ,0.33);

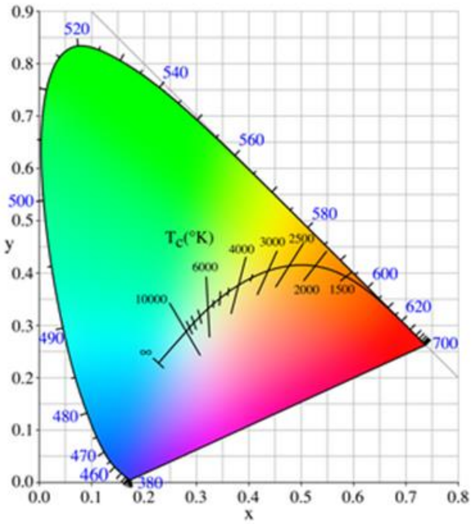


*Figure 1-5: The CIE 1931 x,y chromaticity space, also showing the chromaticities of black-body light sources of various colour temperatures (Tc), and lines of constant correlated colour temperature (Tcp).*

- **Colour temperature, Tc[K]**
  Temperature of a Planckian radiator whose radiation has the same chromaticity as that of a given stimulus;
- **Correlated colour temperature, Tcp[K]**
  Temperature of a Planckian (black body) radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions. The recommended method for calculation is included in CIE publication 15[19];
- **Standard Deviation Colour Matching, SDCM (IEC 62717)**
  SDCM has the same meaning as a MacAdam ellipse. A 1-step MacAdam ellipse defines a zone in the CIE 1931 2 deg (xy) colour space within which the human eye cannot discern colour difference;
- **Lamp gain factor, LGF (defined in previous preparatory studies)**
  a correction factor for lamp efficacy to take into account the higher apparent luminance of white light sources in mesopic view (see the study on Public Street Lighting ).

Important Luminaire parameters are:

- **Luminous Intensity, I, of a source in a given direction, [cd]**
  Quotient of the luminous flux dΦ leaving the source and propagated in the element of solid angle dΩ

[18] Tristimulus values means the amounts of the three reference colour stimuli required to match the colour of the stimulus considered (e.g. a lamp). As the sum of three chromaticity coordinates equals 1, two of them are sufficient to define a chromaticity.
[19] CIE 15: 2004 Colorimetry, 3rd ed.

$$I = \frac{d\Phi}{d\Omega};$$

- **Light distribution and/or luminaire efficiency**
  especially for more energy efficient lamp retrofit solutions and directional light sources; this distribution can be given in different forms (flux code, polar intensity curve, Cartesian diagram or illuminance cone diagram) but should at least be available as CEN / CIE flux code. The CEN (or CIE) flux code (source EN 13032-2) represents the optical characteristics of the luminaire, and consists of 9 whole numbers separated by spaces defined as shown in the list below and Figure 1-6:

| | |
|---|---|
| FCL1/FCL4 | = N1 |
| FCL2/FCL4 | = N2 |
| FCL3/FCL4 | = N3 |
| DFF | = N4 |
| RLOW | = N5 |
| FCU1/FCU4 | = N6 |
| FCU2/FCU4 | = N7 |
| FCU3/FCU4 | = N8 |
| UFF | = N9 |

- **UFF is upward flux fraction** (= **RULO** /LOR= 1-DFF)
- **DFF is downward flux fraction** = **RDLO** /LOR)
- **RLOW is light output ratio working**.
- FCL1-4 are accumulated luminous fluxes in lower hemisphere for the four zones from 0° to 41.4° (FCL1), 60° (FCL2), 75.5° (FCL3) and 90° (FCL4).
- FCU1-4 are accumulated luminous fluxes in upper hemisphere for the four zones from 180° to 138.6° (FCU1), 120° (FCU2), 104.5° (FCU3) and 90° (FCU4);

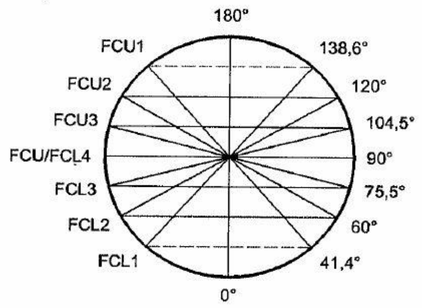


*Figure 1-6: Zones for the calculation of accumulated luminous fluxes according to the CEN flux-code.*

- **light output ratio (of a luminaire), RLO**
  ratio of the total flux of the luminaire, measured under specified 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 (LOR= RLO);
- **light output ratio working (of a luminaire), RLOw**
  ratio of the total flux of the luminaire, measured under specified practical conditions with its own lamps and equipment, to the sum of the individual luminous fluxes of the same lamps when operating

outside the luminaire with a reference ballast, under reference conditions;

- **Polar intensity curve**
  An illustration of the distribution of luminous intensity relative to the light source, in Cd/1000 lm, for different axial planes of the luminaire. The curve provides a visual guide to the type of distribution expected from the luminaire e.g. wide, narrow, direct, indirect etc. in addition to intensity. For a DLS, the distribution is normally symmetric in all planes. This is illustrated in Figure 1-7 where the planes C0-C180 and C90-C270 are covering each other. For LED luminaires it is also possible to have light distributions in absolute photometry in Luminous Intensity Cd (EN 13032-4);

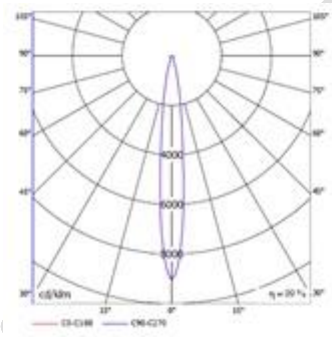

*Figure 1-7: Example of a polar intensity curve*

- **Cartesian light distribution diagram**
  A Cartesian diagram is generally used for floodlights; this also indicates the distribution of luminous intensity, in cd/1000 lm, for different axial planes of the luminaire and provides a visual guide to the type of distribution expected from the luminaire e.g. narrow or wide beam etc., in addition to intensity. On this curve the beam angle can easily be defined.

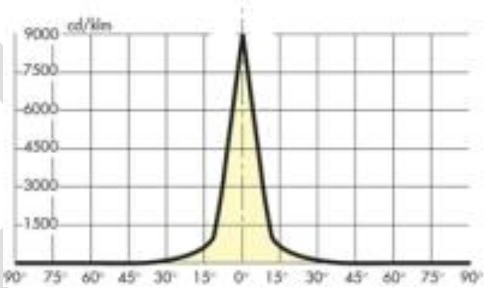


*Figure 1-8: Example of a Cartesian light distribution diagram*

- **Illuminance cone diagram**
  An illuminance cone diagram is usually used for spotlights or lamps with reflectors. The diagram indicates the maximum illuminance, $E_{lux}$, at different distances, plus the beam angle of the lamp over which the luminous intensity drops to 50%. The beam diameter at 50% peak intensity, relative to distance away, is also shown;

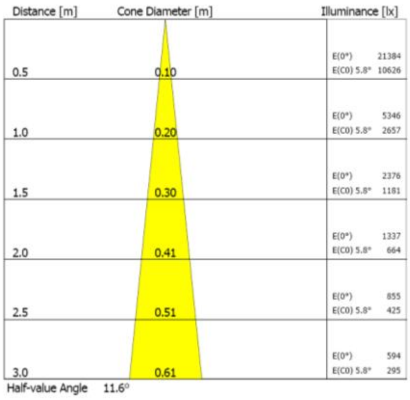


*Figure 1-9: Example of an Illuminance Cone Diagram*

- **Beam angle**
  The angle between those points on opposite sides of the beam axis where the intensity drops to 50% of the maximum, mostly specified on the Cartesian light distribution diagram.
  The beam can also be defined by a solid angle; the mathematical relationship between the solid angle (Ω) of the beam and the beam angle (θ) in ° is:
  $$\Omega \text{ [sr]} = 2\pi * (1 - \cos \theta/2)$$
- **Peak intensity, [cd]**
  The maximum luminous intensity (normally in the centre of the beam angle), see standard EN 61341;
- **Ingress protection code IP $X_1$ $X_2$**
  $X_1$ indicates the degree that equipment is protected against solid foreign bodies intruding into an enclosure,
  $X_2$ indicates the degree of protection of the equipment inside the enclosure against the harmful entry of various forms of moisture;
- **Luminaire maintenance factor, $F_{LM}$**
  defined as the ratio of the light output ratio of a luminaire at a given time to the initial light output ratio;
- **LED luminaire rated life, Lx**
  length of time during which a LED module provides more than claimed percentage x of the initial luminous flux, under standard conditions (ZVEI definition);
- **LED luminaire failure fraction, Fy** (IEC 62717)
  at their rated life designates the percentage (fraction) of failures;
- **LED luminaire gradual failure fraction, By** (IEC 62717)
  The percentage of LED luminaires that fall below the target luminous flux of x percent (see x of Lx) at the end of their designated life;
- **LED luminaire catastrophic failure rate, Cz** (IEC 62717)
  The percentage of LED luminaires that have failed completely by the end of rated life 'Lx'is expressed by 'Cz';
- **rated ambient temperature performance, tp (°C)** (IEC 62717)
  highest ambient temperature around the luminaire related to a rated performance of the luminaire under normal operating conditions, both as declared by the manufacturer or responsible vendor. Note: where a rated ambient performance temperature tp other than 25 °C is advised by the manufacturer a correction factor will need to be established to correct the measured luminous flux value at 25 °C to the luminous flux

value at the declared ambient. This shall be done using relative photometry in a temperature controlled cabinet.

Important Installation parameters are:

- **Utilization factor, $F_U$**
  ratio of the luminous flux received by the reference surface to the sum of the individual total fluxes of the lamps of the installation. Note that the UF is not only dependent on the luminaire itself but also on the accordance between the light distribution and the geometry of the surface to be lit and especially on the exact installation of the luminaire (putting into service);
- **Utilance of an installation for a reference surface, U**
  ratio of the luminous flux received by the reference surface to the sum of the individual total fluxes of the luminaires of the installation (IEC 50/CIE 17.4). It can be calculated analytically from the geometry and light distribution such as in EN 13201-2 or with lighting design software;
- **Useful Utilance for a reference surface, UU (prEN13201-6)**
  ratio of the minimum luminous flux received by the reference surface to the sum of the individual total fluxes of the luminaires of the installation to achieve the minimum required illumination/luminance;
- **Correction factor for over-lighting, $C_L$ (prEN13201-5) or $F_{CL}$** (this study)
  ratio of the luminous flux just sufficient to comply with the lighting requirements received by the reference surface to the (actual) luminous flux received by the reference surface. The luminous flux sufficient to comply with the lighting requirements (=Em,min/Em),

where:

Em,min is the required minimum average illuminance.

- For road lighting requirements based on luminance:

Em,min=Lmin/0,07

- For requirements based on hemispherical illuminance:

Em,min=Ehs/0,65

Correction and conversion factor for over lighting and for luminance or hemispherical illuminance based lighting designs CL;

- **Room surface maintenance factor, $F_{RSM}$**
  is a factor that takes into account the decrease of the reflectance of the walls and ceilings during the use phase;
- **Other important installation parameters such as reflection coefficients of surfaces and geometry are defined in Task 3.**

**The generic formula to calculate the functional unit from the secondary lighting system performance parameters is included in Figure 1-1. Figure 1-2 contains the formulas for road lighting and Figure 1-3 for indoor lighting.**

**Examples of other important performance parameters are:**

- **Operational lifetime**
  A combination of LSF and LLMF newly introduced in some draft standards (EN 62612)
  Length of time during which a lamp provides more than xx% of the original, rated luminous flux (e.g. LLMF ≥ 0.70 or ≥ 0.50 indicated as

$L_{70}$ or $L_{50}$) and the maximum failure rate[20] is still lower than yy% (e.g. LSF ≥ 0.5 or ≥ 0.9 indicated as $F_{50}$ or $F_{10}$);.
- **Power quality**
  Power factor and harmonic currents, see standard EN 61000-3-2.
- **Unit purchase cost**
- **Lamp dimensions and sockets**
  especially for more energy efficient lamp retrofit solutions.

**Conclusion:**
The technical description of a lighting system is based on an extended set of secondary performance parameters. Many of these secondary parameters are used by the lighting designer to optimise the system performance. Optimising the lighting system is far more complex than simply increasing the lamp efficacy, and this will be illustrated in Tasks 3 and 4 that make use of these parameters. The latter are well described and defined in standards.

## 1.4 Overview and description of test standards

**Objective:**
According to the MEErP the aim of this task is to: Identify and shortly describe EN or ISO/IEC test standards, mandates issued by the European Commission to the European Standardisation Organisations, test standards in individual Member States and third countries (if relevant) regarding the test procedures for primary and secondary functional performance parameters on: resources use, emissions, safety, noise and vibrations (if applicable) or other factors that may pose barriers for potential Ecodesign measures. The purpose is also to conduct a comparative analysis for overlapping test standards. Finally the aim is also to: analyse and report new test standards under development; identify possible problems concerning accuracy, reproducibility and to what extend the test standards reflect real-life conditions; draft outlines of mandate(s) to the ESOs as appropriate; and identify differences between standards covering the same subjects (comparative analysis).

### 1.4.1 Background information on European and International standardization bodies

**CEN**, the European Committee for Standardization is an international non-profit organisation.

Through its services, CEN provides a platform for the development of European Standards (ENs) and other consensus documents. CEN's 33 National Members work together to develop these publications in a large number of sectors to help build the European internal market in goods and services, removing barriers to trade and strengthening Europe's position in the global economy.

CEN is working to promote the international harmonisation of standards in the framework of technical cooperation agreements with ISO (International Organization for Standardization).

**CENELEC**

CENELEC is the European Committee for Electrotechnical Standardization and is responsible for standardization in the electrotechnical engineering field. CENELEC

[20] Failure rate $F_x$ is the percentage of a number of tested lamps that have reached the end of their individual lives; $F_x = 100 (1 – LSF)$.

prepares voluntary standards, which help facilitate trade between countries, create new markets, cut compliance costs and support the development of a Single European Market.

CENELEC creates market access at European level but also at international level, adopting international standards wherever possible, through its close collaboration with the International Electrotechnical Commission (IEC).

**CEN and CENELEC** work in a decentralized way. Its members – the National Standardization Bodies (NSBs) of the EU and EFTA countries – operate the technical groups that draw up the standards; the CEN-CENELEC Management Centre (CCMC) in Brussels manages and coordinates this system.

Designated as European Standards Organizations by the European Commission, CEN and CENELEC are non-profit technical organizations.

**European Standards (EN)**
A standard is a publication that provides rules, guidelines or characteristics for activities or their results, for common and repeated use. Standards are created by bringing together all interested parties including manufacturers, users, consumers and regulators of a particular material, product, process or service. Everyone benefits from standardisation through increased product safety and quality as well as lower transaction costs and prices.

A European Standard (EN) is a standard that has been adopted by one of the three recognized European Standardisation Organisations (ESOs): CEN, CENELEC or ETSI. It is produced by all interested parties through a transparent, open and consensus based process.

European Standards are a key component of the Single European Market. Although rather technical and often unknown to the public and media, they represent one of the most important issues for businesses. Often perceived as boring and not particularly relevant to some organisations, they are actually crucial in facilitating trade and hence have high visibility among manufacturers inside and outside Europe. A standard represents a model specification, a technical solution against which a market can trade. It codifies best practice and is usually state of the art.

In essence, European Standards relate to products, services or systems. Today, however, standards are no longer created solely for technical reasons but have also become platforms to enable greater social inclusiveness and engagement with technology, as well as convergence and interoperability within growing markets across industries.

Developing a European Standard
The development of an EN is governed by the principles of consensus, openness, transparency, national commitment and technical coherence (more information is given in the BOSS - Business Operation Support System - Production processes) and follows several steps:

Publication of the EN
After its publication, a European Standard must be given the status of national standard in all CEN member countries, which also have the obligation to withdraw any national standards that would conflict with it. This guarantees that a manufacturer has easier access to the market of all these European countries when applying European Standards and applies whether the manufacturer is based in the CEN territory or not.

Review of the EN
To ensure that a European Standard is still current, it is reviewed at least within five years from its publication.
This review results in the confirmation, modification, revision or withdrawal of the EN.

The concept of Harmonised Standards
The European Standards Organisations (ESOs) CEN, CENELEC and ETSI are involved in a successful partnership with the European Commission and the European Free Trade Association. The ESOs support European legislation in helping the implementation of the European Commission directives, particularly those developed under the New Approach.

To support its policies and legislation, the European Commission requests the ESOs to develop and adopt European Standards, by means of 'standardisation mandates'. Those European Standards developed in response to a mandate are called 'Harmonised Standards'. A list of Harmonized Standards supporting EU Directives and Regulations is available in a dedicated area on the European Commission website.

**Local standards in EU28 members states (DIN, ÖNORM, NBN, NF, ..)**
Members[21] of the CEN and CENELEC can also have local standards. This is in Europe still common practice for installation standards, because they do not conflict with the free movement of goods within the EU and are fitted to the local situation. For example some member states implement their EPBD directive (see1.5.1) calculation method in a local standard (DIN 18599 part 4, ÖNORM H 5059, ..) (see section 1.4.2).

**Beyond Europe**
European Standards are drafted in a global perspective. CEN has signed the 'Vienna Agreement' with the International Organization for Standardization **(ISO)**, through which European and international standards can be developed in parallel. About 30 % of the ENs in the CEN collection are identical to ISO standards. These EN ISO standards have the dual benefits of automatic and identical implementation in all CEN Member countries, and global applicability.

The **International Electrotechnical Commission (IEC),** founded in 1906, is the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

Over 10 000 experts from industry, commerce, government, test and research labs, academia and consumer groups participate in IEC Standardization work.
These are known collectively as "electrotechnology".

IEC provides a platform to companies, industries and governments for meeting, discussing and developing the International Standards they require.
All IEC International Standards are fully consensus-based and represent the needs of key stakeholders of every nation participating in IEC work. Every member country, no matter how large or small, has one vote and a say in what goes into an IEC International Standard.

Over 10 000 experts from industry, commerce, government, test and research labs, academia and consumer groups participate in IEC Standardization work.
The IEC is one of three global sister organizations (IEC, ISO, ITU) that develop International Standards for the world.

When appropriate, IEC cooperates with ISO (International Organization for Standardization) or ITU (International Telecommunication Union) to ensure that

[21] http://standards.cen.eu/dyn/www/f?p=CENWEB:5

International Standards fit together seamlessly and complement each other. Joint committees ensure that International Standards combine all relevant knowledge of experts working in related areas.

**ISO (International Organization for Standardization)** is the world's largest developer of voluntary International Standards. International Standards give state of the art specifications for products, services and good practice, helping to make industry more efficient and effective. Developed through global consensus, ISO helps to break down barriers to international trade.

ISO develops International Standards. It was founded in 1947, and since then ISO has published more than 19 500 International Standards covering almost all aspects of technology and business. From food safety to computers, and agriculture to healthcare.
Today ISO has members from 164 countries and 3 368 technical bodies to take care of standard development. More than 150 people work full time for ISO's Central Secretariat in Geneva, Switzerland. ISO/TC 274 focuses on 'Light and lighting' and does standardization in the field of application of lighting in specific cases complementary to the work items of the International Commission on Illumination (CIE) and the coordination of drafts from the CIE, concerning vision, photometry and colorimetry, involving natural and man-made radiation over the UV, the visible and the IR regions of the spectrum, and application subjects covering all usage of light, indoors and outdoors, energy performance, including environmental, non-visual biological and health effects.

The **International Commission on Illumination** - also known as the **CIE** from its French title, the Commission Internationale de l'Eclairage - is devoted to worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, colour and vision, photobiology and image technology.

With strong technical, scientific and cultural foundations, the CIE is an independent, non-profit organization that serves member countries on a voluntary basis. Since its inception in 1913, the CIE has become a professional organization and has been accepted as representing the best authority on the subject and as such is recognized by ISO as an international standardization body.

Many CIE standards become European Standards (EN) with no or only few modifications.

ETSI, the **European Telecommunications Standards Institute**, produces globally-applicable standards for Information and Communications Technologies (ICT), including fixed, mobile, radio, converged, broadcast and internet technologies.

### 1.4.2 Description of different standards

**Approach:**
In this section a limited list of standards are described that are most relevant for the study. The full list of standards is given in Annex A.

First of all it must be stated that currently there are almost no standards for lighting 'systems'; there are mainly standards for parts of the systems.

These standards can be classified into the following categories:

- safety (electrical, photo-biological, etc.)
- performance (electrical, energy, lighting , dimensions, etc.)
- lighting requirements.

#### *1.4.2.1 The few specific standards for lighting system guidelines*

**CIE 97(2005): Guide on the maintenance of indoor electric lighting systems**

Scope:

During the life of a lighting installation, the light available for the task progressively decreases due to accumulation of dirt on surface and aging of equipment. The rate of reduction is influenced by the equipment choice and the environmental and operating conditions. In lighting scheme design we must take account of this fall by the use of a maintenance factor and plan suitable maintenance schedules to limit the decay. Lighting standard "ISO 8995/CIE S 008-2001 Lighting of Indoor Workplaces" in Section 4.8, recommends a minimum maintenance factor. It states that "The lighting scheme should be designed with overall maintenance factor calculated for the selected lighting equipment, space environment and specified maintenance schedule". A high maintenance factor together with an effective maintenance programme promotes energy efficient design of lighting schemes and limits the installed lighting power requirements.

This revision of the guide describes the parameters influencing the depreciation process and develops the procedure for estimating the maintenance factor for indoor electric lighting systems. It provides information on the selection of equipment estimation of economic maintenance cycles and gives advice on servicing techniques. It shows some examples of data but for accurate data it recommends that data should be obtained from the manufacturers.

Important definitions and data from this guide:

It defines the maintenance factor **(MF**) as a multiple of factors:

MF = LLMF x LSF x LMF x RSMF

Where,

**LLMF** is the lamp lumen maintenance factor;
**LSF** is the lamp survival factor (used only for group replacement programmes);
**LMF** is the luminaire maintenance factor;
**RSMF** is the room surface maintenance factor
Noted: The examples of luminaire maintenance factors (LMF) in Table 3.4 are high, e.g. an open top housing luminaire cleaned every two year would have an LMF of 0.80.

Identified gap:

The example values included are conservative, which results in over dimensioning lighting systems.

Updates might be needed for LED luminaires which were not detailed in this guideline (2005)

ZVEI has a 'Guide to Reliable Planning with LED Lighting Terminology, Definitions and Measurement Methods: Bases for Comparison'[22] where also the Lamp Survival Factor (**LSF**) is taken into account for lighting systems using multiple LED sources. This could be included in an update.

Input received from IALD[23]:

[22] http://www.zvei.org/Publikationen/Guide%20to%20Reliable%20Planning%20LED%20Lighting%202013-11.pdf

[23] http://www.iald.org/

"Calculation of Maintenance Factors remains an area where the experience of the lighting designer could provide a more comprehensive solution. The values stated are not necessarily conservative. In use the majority of lighting installations do not receive adequate maintenance and cleaning. Current marketing trends suggesting that LED luminaires require little or no maintenance could potentially contribute to worsening the situation. Currently recommended lighting levels are based on the end of life performance of a lighting system. This results in over dimensioning when the lifetime of the system is expected to be very long."

Note: CIE 97:2005 is on the list of CIE division 3 as required an update but there is currently no work in progress. Revision is also foreseen in ISO/TC-274.

**CIE 154(2003): 'The maintenance of outdoor lighting systems'**

Scope:

During the life of a lighting installation, the light available progressively decreases. The reduction rates are a function of environmental, operating and age conditions. In lighting design we must take account of this fall by the use of a maintenance factor and plan suitable maintenance schedules to limit the decay. This guide provides information on suggested maintenance factors and the selection of suitable equipment. It describes the parameters influencing the depreciation process and develops the procedure for estimating the economic maintenance cycles for outdoor electric lighting installations and gives advice on servicing techniques

Important definitions and data from this guide:

Luminaire Maintenance Factor (LMF) is defined as the ratio of the light output ratio of a luminaire at a given time to the initial light output ratio.
It depends strongly on environmental pollution and the quality of the optical system, especially on the protection class (IP-rating) of the optical compartment. The IP-ratings are defined in standard EN 60529: 'Degrees of protection provided by enclosures (IP Code)'. So an important segmentation will be made by distinction of the IP-rating.

Identified gap:

Updates might be needed for LED luminaires which were not detailed in this guideline (2007). ZVEI has a 'Guide to Reliable Planning with LED Lighting Terminology, Definitions and Measurement Methods: Bases for Comparison'[24] where also the Lamp Survival Factor (**LSF**) is taken into account for lighting systems using multiple LED sources. This could be included in an update.

Input received from IALD (see also CIE 97):

"Calculation of Maintenance Factors remains an area where the experience of the lighting designer could provide a more comprehensive solution. The values stated are not necessarily conservative. In use the majority of lighting installations do not receive adequate maintenance and cleaning. Current marketing trends suggesting that LED luminaires require little or no maintenance could potentially contribute to worsening the situation. Currently

[24] http://www.zvei.org/Publikationen/Guide%20to%20Reliable%20Planning%20LED%20Lighting%202013-11.pdf

recommended lighting levels are based on the end of life performance of a lighting system. This results in over dimensioning when the lifetime of the system is expected to be very long."

Note: CIE 97:2005 is on the list of CIE division 3 as requiring an update but there is currently no work in progress. Revision is also foreseen in ISO/TC-274.

**EN 50172: 'Emergency escape lighting systems.'**

Scope:

This Standard specifies the provision of illumination of escape routes and safety signs in the event of failure of the normal supply, and specifies the minimum provision of such emergency lighting based on the size, type and usage of the premises. This standard relates to the provision of electric emergency escape lighting in all work places and premises open to the public. This Standard does not cover private residential premises but its provisions are applicable to common access routes within multi-storey dwellings. This Standard is also applicable to standby lighting used as emergency escape lighting. There are emerging way guidance techniques that, when applied to escape routes in addition to conventional emergency lighting luminaires, can enhance its effectiveness in an emergency.

This standard covers a variety of topics, including emergency escape lighting, the design of emergency lighting, as well as the required system records and log book. It also give best practice recommendation on the servicing and testing of emergency lighting systems.

The preceding standard is related to:

**EN 50171: 'Central power supply systems.'**

Scope:

This European Standard specifies the general requirements for central power supply systems for an independent energy supply to essential safety equipment. This standard covers systems permanently connected to AC. supply voltages not exceeding 1 000 V and that use batteries as the alternative power source. The central power supplies are intended to energise emergency escape lighting in the case of failure of the normal supply, and maybe suitable for energising other essential safety equipment for example: - electrical circuits of automatic fire extinguishing installations, - paging systems and signalling safety installations, - smoke extraction equipment, - carbon monoxide warning systems, - specific safety installations related to specific buildings e.g. high-risk areas. Schematic representations of typical central power supply equipment are depicted in clause 4. When a UPS system is used to feed these essential safety systems, it must comply with EN 50091-1 and its relevant parts, and the additional requirements of this standard. The power supply system for fire alarms covered by EN 54 are excluded.

### 1.4.2.2 European standards defining energy performance of lighting installations or systems

**EN 15193 (2007): 'Energy performance of buildings – Energy requirements for lighting'**

Important Notice: This standard is currently under revision, this section will be updated in the course of this study. The new version will contain two parts.

Scope:

This European Standard specifies the calculation methodology for the evaluation of the amount of energy used for indoor lighting inside the building and provides a numeric indicator for lighting energy requirements used for certification purposes. It can be used for existing buildings and for the design of new or renovated buildings. It also provides reference schemes to base the targets for energy allocated for lighting usage. The standard also provides a methodology for the calculation of instantaneous lighting energy use for the estimation of the total energy performance of the building. Parasitic powers not included in the luminaire are excluded.

In this standard buildings are classified in the following categories: offices, education buildings, hospitals, hotels, restaurants, sports facilities, wholesale and retail services and manufacturing factories.

In some locations outside lighting may be fed with power from the building. This lighting may be used for illumination of the façade, open-air car park lighting, security lighting, garden lighting etc. These lighting systems may consume significant energy and if they are fed from the building, this load will not be included in the Lighting Energy Numeric Indicator (LENI) or into the values used for heating and cooling load estimate. If metering of the lighting load is employed, these loads may be included in the measured lighting energy.

Note according to IALD[23]:

"Lighting control system development is currently outpacing the ability of standards to keep up with the potential. Mandating adherence to standards such as these risks inhibiting new developments and consequent energy savings. Using a measure such as LENI allows for a technologically blind assessment of energy used."

Important definitions from this standard:

The general context of this standard and its relations to other standards is included in Figure 1-3.

The most relevant output parameter Lighting Energy Numerical Indicator **(LENI)** [kWh/(m².time period)]. Therefore it provides methods to calculate a Constant illumination Factor (**Fc**), a Daylight depedency Factor (**Fd**) and an Occupancy dependency factor (**Fo**). Operational hours are derived from EN 15251.
From the lighting design and/or luminaire factor input data on Luminaire Power (**Pl),** Luminaire emergency standby power (**Pem**), Luminaire control standby power (**Ppc**).

The standard defines three methods as illustrated in Figure 1-10. The luminaire power is the power needed to have a lighting system compliant with minimum illumination requirements obtained from EN 12464, this can be done with lighting design software or from formulas in standard EN 13032.

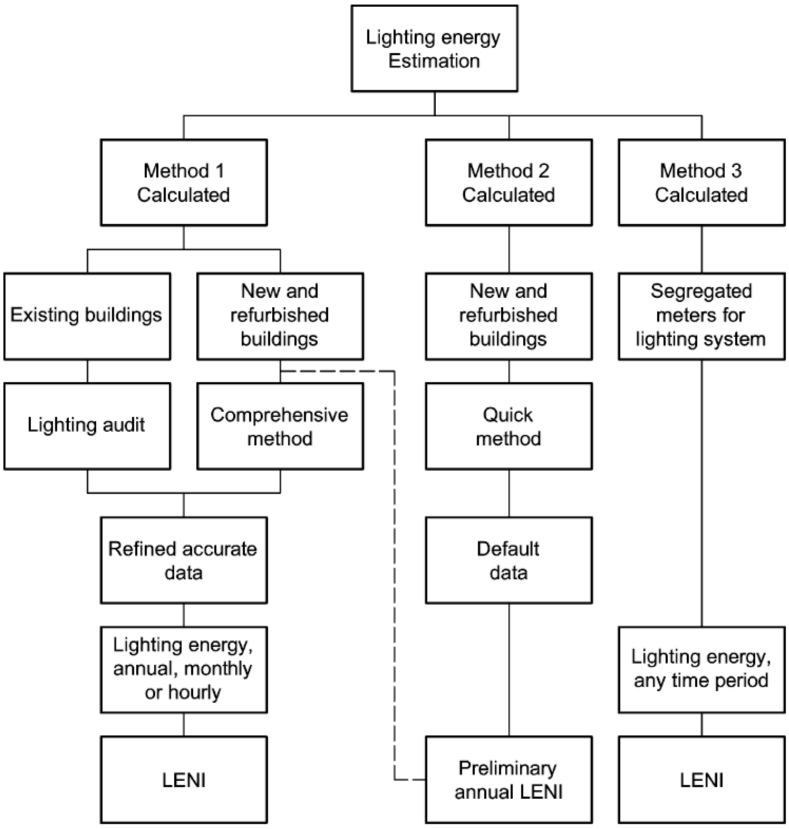


*Figure 1-10: Flow chart illustrating alternative routes to determine energy use in prEN 15193-1*

The updated version includes a method based on so-called expenditure factors that disaggregates data into systems levels similar to this study and compares it to reference values. To be updated at the end of the study.

In Annex G (draft 2014) on Constant Illuminance, the **MF** is defined as the ratio between maintained illuminance and initial illuminance. The MF is made up of multiple factors such as LLMF, LSF, LMF, and RSMF. Full details of the derivation of the MF can be found in CIE 97.

Annex F of the 2007 version contained benchmark values, Figure 1-11. The proposal is to include them in Annex K of prEN 15193-2 (version 2014).

**Annex F**
(informative)
**Benchmark values and lighting design criteria**
**Table F.1 — Bench mark default value**

| | | | | PN | $t_D$ | $t_N$ | $F_c$ | | $F_o$ | | $F_D$ | | *LENI* | *LENI* | *LENI* | *LENI* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Qual. class | Parasitic Emergency kWh/(m²/year) | Parasitic Control kWh/(m²/year) | W/m² | h | h | no cte illiminance | cte illiminance | Manu | Auto | Manu | Auto | Limiting value Manu kWh/(m²/year) | Auto | Limiting value Manu kWh/(m²/year) | Auto |
| Office | * | 1 | 5 | 15 | 2250 | 250 | 1 | 0,9 | 1 | 0,9 | 1 | 0,9 | 42,1 | 35,3 | 38,3 | 32,2 |
| | ** | 1 | 5 | 20 | 2250 | 250 | 1 | 0,9 | 1 | 0,9 | 1 | 0,9 | 54,6 | 45,5 | 49,6 | 41,4 |
| | *** | 1 | 5 | 25 | 2250 | 250 | 1 | 0,9 | 1 | 0,9 | 1 | 0,9 | 67,1 | 55,8 | 60,8 | 50,6 |
| Education | * | 1 | 5 | 15 | 1800 | 200 | 1 | 0,9 | 1 | 0,9 | 1 | 0,8 | 34,9 | 27,0 | 31,9 | 24,8 |
| | ** | 1 | 5 | 20 | 1800 | 200 | 1 | 0,9 | 1 | 0,9 | 1 | 0,8 | 44,9 | 34,4 | 40,9 | 31,4 |
| | *** | 1 | 5 | 25 | 1800 | 200 | 1 | 0,9 | 1 | 0,9 | 1 | 0,8 | 54,9 | 41,8 | 49,9 | 38,1 |
| Hospital | * | 1 | 5 | 15 | 3000 | 2000 | 1 | 0,9 | 0,9 | 0,8 | 1 | 0,8 | 70,6 | 55,9 | 63,9 | 50,7 |
| | ** | 1 | 5 | 25 | 3000 | 2000 | 1 | 0,9 | 0,9 | 0,8 | 1 | 0,8 | 115,6 | 91,1 | 104,4 | 82,3 |
| | *** | 1 | 5 | 35 | 3000 | 2000 | 1 | 0,9 | 0,9 | 0,8 | 1 | 0,8 | 160,6 | 126,3 | 144,9 | 114,0 |
| Hotel | * | 1 | 5 | 10 | 3000 | 2000 | 1 | 0,9 | 0,7 | 0,7 | 1 | 1 | 38,1 | 38,1 | 34,6 | 34,6 |

*Figure 1-11: Fragment of benchmark values contained in AnnexF of standard EN 15193(2007)*

In the version of 2007 Annex F contained benchmark values

Identified gaps[25](2007 version):

The European Commission initiated the CENSE-project to improve acceptance and use of the CEN standards, which were developed to analyse the energy performance of buildings, including lighting, according to the EPBD. The project's goal is to identify problems concerning the standards' contents and their implementation via questionnaires and workshops and to formulate recommendations for improvement.

Within the framework of the CENSE-project the standard EN 15193, covering the energy requirements for lighting, was investigated. The questionnaire's evaluation shows that though lighting requirements have been defined in most European countries, only few countries did actually put the CEN standard into force; also, awareness of practitioners is still low. In general, the standard is regarded as a useful umbrella document and its methods are considered to be applicable and helpful. Nevertheless, parts of the standard are rated being not easy to understand. Although many essential parameters in the determination of lighting energy needs are covered, some additional aspects should be addressed in a revised version. Providing, for instance, methods to rate lighting controls in more detail, to determine the installed power of new lighting installations and to rate the impact of sun-shading devices on the lighting energy demand might help to further improve the standard's quality and acceptance. A simple means to raise acceptance, formulated in the CENSE project, is to l review the standard focusing on structure and editing in order to clarify and simplify parts of the document. Particularly the presentation of equations should be reorganized, for instance by adding a list of the variables used to each equation and by describing connections to other equations, making them more understandable. An example of technical aspects still to be addressed is artificial lighting, which is only taken care of in existing buildings in the current version of the standard. Consequently, an additional approach covering the lighting design in new buildings needs to be developed, and a simplified method should be included. Also the effect of lighting controls should be considered in the calculation method

[25] Report on the Application of CEN Standard EN 15193 EN 15193: Energy Performance of Buildings - Energy Requirements for Lighting, Anna Staudt, Jan de Boer and Hans Erhorn

as well as the impact of glare and sun-shading protection on lighting energy demand. By providing extra material with simplified explanations and background information, the readers' ability to understand and apply the standard could be further enhanced as well as their awareness of the methods underlying available computer software.

Potential gaps in prEN15293-1&2(2014):

Links with other standards are not fully documented. There is no direct cross reference to EN 15232 on building automation. There is also no reference included to any specific standard in shading devices. Cross checking, updating and aligning acronyms with EN 12665. This could allow that similar acronyms and parameters are used in similar standards (e.g. EN 13201-5).
The impact of shading devices is included in Table F.7: all venetian blinds are treaded equal and horizontal versus vertical blinds are not discriminated.
It does not specify the optical calculation method and/or software to obtain the required Power to satisfy EN 12464 illumination requirements.
It does not cover all innovative control systems defined in section 1.3.2.3.1. Therefore some extra factors could be added for other innovations, e.g. a user comfort setting factor (Fcu) and relocation flexibility factor (Fre).

There is a measurement method defined for the LENI but it does not take into account that occupancy is variable and can have a big impact. It is therefore recommended that occupancy is measured and quantified separately and taken into account properly. This method could be included in EN 15232 on building automation and cross references could be added.

Should member states vote positively for this standard it is unclear whether they would also fully support implementing it into their EPBD legislation (it was not in the previous version). There could be a request for more simple methods that grant full benefits to systems composed of the best light sources and control systems without going into building design and user assumption details.

Reference is made to CIE 97 in relation to the Maintenance Factor, these values are too pessimistic and might be too high compared to current practices.
In the draft version prEN 15193-2 (draft 2014)
The effect of colour filtering by the glazing is not included.

This standard also refers to EN 12464 for method 1 and therefore the gaps identified in this standard are also valid.

**EN 15232: 'Energy performance of buildings - Impact of Building Automation, Controls and Building Management.'**

Scope:

This European Standard specifies:

a structured list of Building Automation and Control System (BACS) and Technical Building Management (TBM) functions which have an impact on the energy performance of buildings;

a method to define minimum requirements regarding BACS and TBM functions to be implemented in buildings of different complexities;

a factor based method to get a first estimation of the impact of these functions on typical buildings;

detailed methods to assess the impact of these functions on a given building. These methods enable the impact of these functions in the calculations of energy performance ratings and indicators calculated by the relevant standards to be introduced.

Important definitions and data from this standard:

The standard primarily defines four classes that poses specific requirements on control systems including lighting. This types of control system match with EN 15232. It contains a calculation procedures based on BAC efficiency factors, for lighting reference is made to EN 15193.

The 4 classes of Building Automation Systems are:

- Class A: High energy performance building automation and control system (BACS) and technical building management (TBM);
- Class B: Advanced BACS and TBM;
- Class C: Standard BACS;
- Class D: Non energy efficient BACS;

For each class minimum control system requirements are defined, see Figure 1-12.

**Table 1** — *(concluded)*

| | | Definition of classes | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Residential | | | | Non residential | | | |
| | | D | C | B | A | D | C | B | A |
| LIGHTING CONTROL | | | | | | | | | |
| Occupancy control | | | | | | | | | |
| 0 | Manual on/off switch | | | | | | | | |
| 1 | Manual on/off switch + additional sweeping extinction signal | | | | | | | | |
| 2 | Automatic detection Auto On / Dimmed | | | | | | | | |
| 3 | Automatic detection Auto On / Auto Off | | | | | | | | |
| 4 | Automatic detection Manual On / Dimmed | | | | | | | | |
| 5 | Automatic detection Manual On / Auto Off | | | | | | | | |
| Daylight control | | | | | | | | | |
| 0 | Manual | | | | | | | | |
| 1 | Automatic | | | | | | | | |

*Figure 1-12: Table 1 on lighting controls defined in EN 15232*

Afterwards the standard defines relations between building energy systems and so-called BAC efficiency factors for different types of energy use, including lighting, see Figure 1-13. These factors enable savings to be estimated.

Table 10 — BAC/TBM Efficiency factors $f_{BAC,el}$ – Non-residential buildings

| Non-residential building types | BAC efficiency factors $f_{BAC,el}$ | | | |
|---|---|---|---|---|
| | D | C (Reference) | B | A |
| | Non energy efficient | **Standard** | Advanced | High energy performance |
| Offices | 1,10 | 1 | 0,93 | 0,87 |
| Lecture hall | 1,06 | 1 | 0,94 | 0,89 |
| Education buildings (schools) | 1,07 | 1 | 0,93 | 0,86 |
| Hospitals | 1,05 | 1 | 0,98 | 0,96 |
| Hotels | 1,07 | 1 | 0,95 | 0,90 |
| Restaurants | 1,04 | 1 | 0,96 | 0,92 |
| Wholesale and retail trade service | 1,08 | 1 | 0,95 | 0,91 |
| Other types:<br>- sport facilities<br>- storage<br>- industrial buildings<br>- etc. | | 1 | | |

*Figure 1-13: Table 10 on BAC/TBM efficiency factors in EN 15232*

Potential gaps in EN 15232:

The savings obtainable with lighting controls are estimated, and they overlap with the savings projected in EN 15193 and hence risk double counting in the EPBD.

It does not cover all innovative control systems defined in section 1.3.2.3.1.

Reference could be made to EN 12464-1 and that task areas and their surrounding areas can change over the life time of a building, therefore a building management system could flexibly reconfigure the illumination levels and provide additional savings.

The revision of EN 15232 is ongoing and the following comment on this process was received from EU.BAC[26] who participates in the reviewed:

- EN 15232 is currently undergoing a revision under the mandate M/480 and it would be great if lighting systems experts could join either M/480 activities and/or TC 247 maintenance work – including calculation methods in referenced standards;
- New light controls functions to be taken into consideration:
  - Development of advanced lighting controls functions in BACS: the most recent developments concern adapting the light intensity to occupancy, unoccupied/ standby/ occupied functions with either dimming or partial light switch off: this is typically with standby occupancy with presence detection in the building (access control) or level of occupancy (number of people in the room; CCTV, people counting e.g. in public buildings, museum, stations);
  - Ease of reprogramming for the building user to change occupancy modes, avoid fixed programming on a bus;
  - Coupling of shade control with light control like in France;
  - The number of new control technologies available at light point (knx[27], web-lights, PoE[28]) should be considered when updating EN 15232;

[26] http://www.eubac.org/
[27] http://www.knx.org/knx-en/index.php
[28] https://en.wikipedia.org/wiki/Power_over_Ethernet

- The integration of monitoring functions of light control ratio (% of light switched off or dimmed during the year) in the BACS.

**prEN 13201-5: 'Road lighting-Part 5: Energy performance indicators.' (Draft)**
Note: This standard has been adopted, the final version is not yet available.

Scope:

This Draft European Standard EN 13201-5 has been submitted to CEN members for voting. In the event of a positive vote as required by CEN/CENELEC regulations, this Draft will be published as an EN standard.

Annex B defines the 'installation luminous efficacy' ($\eta_{inst}$) which takes over-lighting into account, the formula and related parameters are:

$$\eta_{inst} = C_L.f_M.U.R_{LO}.\eta_{ls}.\eta_P$$

For the definition of parameters used in the formula see section 1.3.3.2.

$C_L$ takes into account over-lighting, the defined installation efficacy does not take into account those benefits of fitting to the minimum requirements and reducing over-lighting.

prEN13201-6 proposed energy indicators:
= CL/ηins =
)
= Σ(Pj x tj)/A
tfull = annual operating hours of the full level illumination
tred = annual operating time of the reduced level illumination
kred = power reduction coefficient for reduced level illumination
Pj = operating power of jth period
tj = duration of jth period over year in hour
ηins = installation efficacy
Note: prEN13201-5 proposes to exclude lumens to satisfy Edge Illumination requirements, e.g. to have light in surrounding areas.

These indicators may be used to compare the energy performance of different road lighting solutions and technologies for the same road lighting project. The energy performance of road lighting systems with different road geometries or different lighting requirements cannot be compared to each other directly, as the energy performance is influenced by, amongst other factors, the geometry of the area to be lit, as well as, the lighting requirements. The power density (D) and energy consumption indicators (ECIy) apply for all traffic areas covered by the series of lighting classes M, C and P as defined in EN 13201-2.
Annex B introduces the installation efficacy and its factors as a measure of the influence of various losses and parameters.

Important definitions from this standard:

This European Standard defines how to calculate two energy performance indicators for road lighting installations, which are the so-called Power Density Indicator (PDI)) or $D_P$[W/(lx.m²)] and the Annual Energy Consumption indicator(AECI) or DE[kWh/(m²y)].

The Power Density Indicator ($D_P$) demonstrates the energy needed for a road lighting installation, while it is fulfilling the relevant lighting requirements specified in EN 13201-2. The annual energy consumption indicator ($D_E$)

determines the power consumption during the year, even if the relevant lighting requirements change during the night or seasons. The luminaire power is the power needed to have a lighting system compliant with minimum illumination requirements obtained from classes defined EN 13201-2, this means that in DE also dimming is taken into account.

The Power density Indicator (DP) is calculated based on the calculated maintained average horizontal illuminances, hence it does not compensate for over-lighting compared to the minimum required illuminance or taking constant light output regulation into account. The PDI and the AECI do not include all the reference sub-areas. Areas of strips for calculation of the edge illuminance ratio are excluded from the calculation of energy performance indicators although requirements apply to these strips.

Because neither DE nor DP cover all improvement options it is important to use both parameters together to assess system efficacy.

In Annex A examples are included, e.g. a road layout as illustrated in Figure 1-14 and Figure 1-15. This could be useful for later tasks.

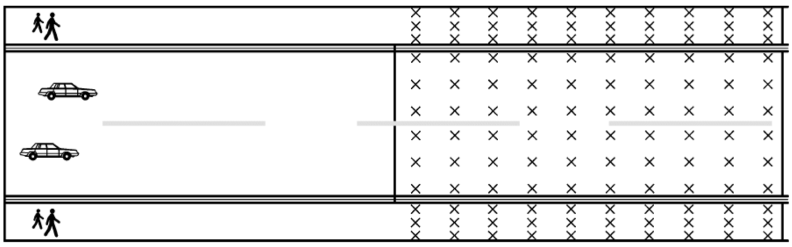

*Figure 1-14: Example of Annex A for Road and two sidewalks in both sides*

Table A.9 — Typical values of the Power Density Indicator $D_P$ in $mW.lx^{-1}.m^{-2}$ for road profile E

| Lighting class | Width of carriageway *m* | Lamp type | | | | |
|---|---|---|---|---|---|---|
| | | Mercury | Metal halide | Sodium elliptical | Sodium tubular | LED |
| M3/P3 | 7 | 61 | 34 | 29 | 24 - 33 | 17 - 18 |
| M4/P4 | 7 | 65 | 41 | 33 - 34 | 26 - 28 | 17 |
| M5/P5 | 7 | 63 | 22 | 33 | 28 - 32 | 17 |

Table A.10 — Typical values of the Annual Energy Consumption Indicator $D_E$ in $kWh.m^{-2}$ for road profile E

| Lighting class | Width of carriageway *m* | Lamp type | | | | |
|---|---|---|---|---|---|---|
| | | Mercury | Metal halide | Sodium elliptical | Sodium tubular | LED |
| M3/P3 | 7 | 3,8 | 2,3 | 1,8 – 2,0 | 1,6 | 1,0 |
| M4/P4 | 7 | 3,2 | 2,0 | 1,5 | 1,2 - 1,5 | 0,7 |
| M5/P5 | 7 | 2,0 | 0,6 | 1,0 | 0,7 - 1 | 0,5 |

**A.3.7 Road and two sidewalks on both sides separated from carriageway by grass strips (road profile F)**

*Figure 1-15: Typical power density (DP) and energy consumption (DE) values in prEN13201-5*

Annex B of this standard describes a method for analysing and disaggregating the installation losses into installation efficiency, light source efficacy, periodic reduction factor and power (gear) efficiency. This method (see Figure 1-2) is identical to the system component defined in this study (see Figure 1-1). Therefore Annex B defines the 'installation luminous efficacy' ($\eta_{inst}$) which takes over-lighting into account, the formula and related parameters are:

$$\eta_{inst} = C_L.f_M.U.R_{LO}.\eta_{ls}.\eta_P$$

For definitions of the parameters in the formula see section 1.3.3.2.
$C_L$ takes into account over-lighting. The benefits of constant output regulation (CLO, see also 1.3.2.3.2) are not taken into account.

Potential gaps in EN 13201-5:

A potential weakness is that the decomposition is in Annex B which defines installation efficacy related to subsystems and that Constant Lighting Output regulation is not taken into account.

The PDI and the AECI do not include all the reference sub-areas, which could complicate comparison different street layouts. These issues could be addressed in a newly proposed prEN 13201-6.

**prEN 13201-6:2015 Road Lighting - Part 6: Tables of the most energy efficient useful utilance, utilance and utilization factor**

Scope:

This standard is being developed under the Commission mandate M/485 including also a preparatory study 2014-2015. The standard facilitates a requirement for product information in the Commission Regulation 245/2009 ANNEX VII (on Street Lighting), 3. LUMINAIRE BENCHMARKS, clause 3.2:
"(b) Utilisation Factor values for standard road conditions in tabular form for the defined road class. The table contains the most energy efficient UF values for different road widths, different pole heights, maximum pole distances, luminaire overhang and inclination, as appropriate for the given road class and luminaire design; (c)…"

**EN 50285: 'Energy efficiency of electric lamps for household use - Measurement methods.'**

Scope:

This European Standard has been produced under Standardisation Mandate M/202 in response to the European Commission Directive implementing Council Directive 92/75/EEC with regard to energy labelling of household lamps. A method of classification of lamps according to energy efficiency is given in the Directive and is not a part of this standard. This standard specifies the test conditions and method of measurement of luminous flux, lamp wattage and lamp life as given on a label on the lamp packaging, together with a procedure for verification of the declared values. Only those parameters that are specific to the above mentioned Directive are included in this standard. All other parameters are included in the relevant lamp performance standards. Lamps covered by this standard are: mains voltage tungsten filament lamps;

mains voltage tungsten halogen lamps; self-ballasted lamps; double-capped fluorescent lamps; single-capped fluorescent lamps.

#### 1.4.2.3 Examples of local standards in EU28 member states that are an alternative to EN 15193 for defining lighting energy calculations in their local EPBD implementation

**DIN V 18599 - 4: 'Energy efficiency of buildings - Calculation of the net, final and primary energy demand for heating, cooling, ventilation, domestic hot water and lighting - Part 4: Net and final energy demand for lighting.'**

Country: Germany (Nutz- und Endenergiebedarf für Beleuchtung) and also Luxemburg adopted this standard in their EPBD implementation. This standard is the basis for the German EnEV (Energieeinsparverordnung). The EnEV was established by the government and sets allowable power consumption levels for the entire building including energy consumption for lighting.

Scope:

> DIN V 18599-4 specifies the approved method of verifying the monthly and annual energy use for lighting in non-residential buildings. The method includes the division of a building into zones as required for lighting technology purposes, determination of the specific "electrical evaluation power" of the artificial lighting system, as well as considerations on the way in which daylight is utilized and the effects of presence detection systems. To achieve lighting energy efficiency, suitable lighting and lighting control systems shall be employed and the available daylight shall be utilized to the best possible extent. The method described here only deals with the lighting systems needed to achieve minimum lighting requirements. According to the provisions of DIN EN 12464-1, a lighting system shall be designed in such a way that the lighting requirements of a specific space are met without needlessly increasing energy use. At the same time, energy use shall not be reduced to the detriment of the quality of the lighting conditions. DIN V 18599-4 has been approved by NA 005-56-20 GA "Gemeinschaftsarbeitsausschuss NABau/FNL/NHRS: Energetische Bewertung von Gebäuden" ("Joint Working Committee NABau/FNL/NHRS: Energy performance of buildings") and published as a prestandard.

'The German standardization process (DIN 18599) refined the European approach (EN 15193) in some aspects.

> According to this standard the installed, electrical power of the artificial lighting system can be determined with a simple tabular method, a simplified utilization factor approach or of course a detailed lighting design. Which method to apply depends on the design phase (i.e. availability of data) and the level of effort expended. As depicted in Figure 3 the methods are designed such that accuracy will increase with growing effort.

Please note that the Lot 8 preparatory study on office lighting used and compared the utilization factor method and the lighting design with a simulation approach.

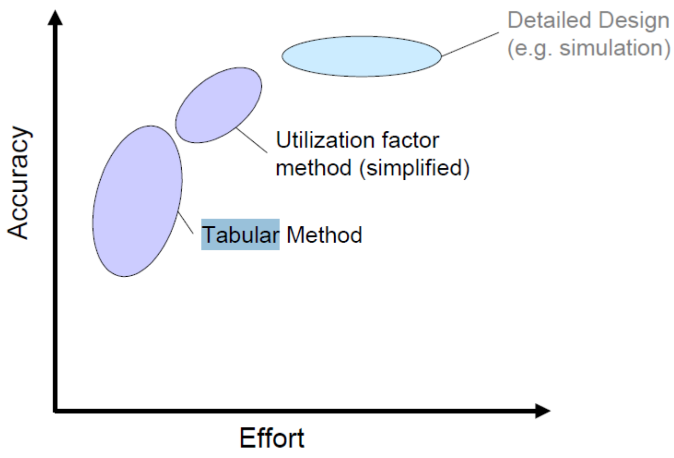


*Figure 1-16: Possible different methods to obtain the installed, electric power*

Some lighting calculation programs can implement this standard (DIN 18599) in their calculations e.g. Dialux and EnerCalC.

Identified gap (source: comments Lighting Europe):
Benchmark values are usually too high compared to using todays LED lighting system. The difference between new and existing installations should be shown.

**ÖNORM H 5059: 'Energy Efficiency of Buildings – Energy demand for lighting'**

Country: Austria (Gesamtenergieeffizienz von Gebäuden – Beleuchtungsenergiebedarf)
Scope:

This is a similar local implemention of an EPBD calculation method to DIN V 18599-4 or EN 15193.

#### *1.4.2.4 The most important standards on lighting requirements*

**EN 12665: 'Light and lighting - Basic terms and criteria for specifying lighting requirements'**

Scope:

This standard defines basic terms for use in all lighting applications; specialist terms with limited applications are given in individual standards. This standard also sets out a framework for the specification of lighting requirements, giving details of aspects which shall be considered when setting those requirements.

**EN 13032-1: 'Light and lighting — Measurement and presentation of photometric data of lamps and luminaires — Part 1: Measurement and file format.'**

Scope:

This European Standard establishes general principles for the measurement of basic photometric data for lighting application purposes. It establishes the measurement criteria needed for the standardisation of basic photometric data and details of the CEN file format for electronic data transfer. This is part 1 of a multi-part standard. Part 1 deals with the basic photometric measurement and file format. Other parts deal with lamps and luminaires data depending on the applications.

Identified gaps:

Despite of this European standard being adopted, the sector often uses another similar file format (EULUMDAT, IES, CIBSE, etc.) in practice, see section 1.3.2.4.
A photometry file reduces a luminaire to a point source which can be inaccurate when modelling a distributed light source such as a large LED panel luminaire (e.g. OLED), therefore more sophisticated file formats are being developed (e.g. IES TM-25-13).

Some programs use specific file formats to overcome this. Dialux (ULD files) and Relux (ROLF files) allow the photometry to be attached to a model of the luminaire, ensuring the correct position of the luminous emitting areas within the luminaire geometry.

For basic photometric file formats the photometry is spread over the luminous area specified within the file, centred upon the centre of the luminaire dimensions. So, for example, a street lantern with the light source positioned at the end of a body containing control gear, spigot mounting mouldings, etc. would have the luminous aperture positioned central to the full body which would be somewhere over the gear compartment. This is because the photometric file conveys the size of the luminaire and the size of the luminous aperture but not any geometric relationship between the two.

**EN 13032-2: ‘Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 2: Presentation of data for indoor and outdoor work places.’**

Scope:

This document specifies the required data for lamps and luminaires for the verification of conformity to the requirements of EN 12464-1 and prEN 12464-2. It also specifies data that are commonly used for lighting of indoor and outdoor work places. When these data are provided, they should conform to this document

When the room parameters, the luminaire data (according to EN 13032-1(2004)) are known this method allows the defined functional unit based on the Utilisation Factor (UF) method to be calculated.

Note:

This standard is derived from the international standard CIE 115. It is worth noting that CIE 115 also includes a total cost of ownership model and a reference calculation.

**EN 13032-3: 'Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 3: Presentation of data for emergency lighting of work places.'**

Scope:

This standard specifies the required data for lamps and luminaires to verify conformity with EN 1838. This standard does not define the data requirements for signage, as these can be found in EN 1838.

**prEN 13032-4: 'Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 4: Presentation of data for LED lamps, modules and luminaires.'**

Scope:

This project for a European Standard specifies the requirements for measurement of electrical, photometric, and colorimetric quantities of LED lamps, modules, light engines and luminaires, for operation with AC or DC supply voltages, possibly with associated control gear. Photometric and colorimetric quantities covered in this standard include total luminous flux, luminous efficacy, partial luminous flux, luminous intensity distribution, centre-beam intensities, luminance and luminance distribution, chromaticity coordinates, correlated colour temperature (CCT), Colour Rendering Index (CRI), and spatial uniformity of chromaticity. This standard does not cover LED packages and products based on OLEDs (organic LEDs).

**IES TM-25-13 'Ray File Format for the Description of the Emission Property of Light Sources.'**

Scope:

This guideline provides recommendations for a standard ray file format to describe the emission properties of light sources. The ray file format contains information necessary to interface between ray tracing or other optical design, simulation, analysis and metrology software used in lighting applications.

Identified gaps:

It is a guideline and not yet a standard.

**EN 1838(2013): 'Lighting applications. Emergency lighting'**

Scope:

This is a European Standard that specifies the luminous requirements for emergency escape lighting and standby lighting systems installed in premises or locations where such systems are required. It is principally applicable to locations where the public or workers have access.

**EN 12464-1:** ***'Light and Lighting-Part 1: Lighting of indoor work places.'***

Scope:

This European standard specifies lighting requirements for indoor work places, which meet the needs for visual comfort and performance. All usual visual tasks are considered, including Display Screen Equipment (DSE).

This European standard does not specify lighting requirements with respect to the safety and health of workers at work and has not been prepared in the field of application of Article 137 of the EC treaty, although the lighting requirements, as specified in this standard, usually fulfil safety needs. Lighting requirements with respect to the safety and health of workers at work may be contained in Directives based on Article 137 of the EC treaty, in the national legislation of member states implementing these Directives or in other national legislation of member states.

This standard neither provides specific solutions, nor restricts the designers' freedom from exploring new techniques nor restricts the use of innovative equipment.

This standard is not applicable for the lighting of outdoor work places and underground mining.

Important definitions and data from this standard:

This standard defines the zoning of work places and their illumination requirements.

It defines therefore amongst others the following areas:

- **Task area** as the area within which the visual task is carried out.
- The **surrounding area** band surrounding the task area within the visual field
- The **area adjacent to the immediate surroundings**.

More information on the selection of these zones can be found in a user guide on this standard available at Licht.de[29].

For the task areas within this standard minimum lighting requirements are defined in Figure 1-17.

[29] http://en.licht.de/fileadmin/shop-downloads/Guide-DIN-EN-12464-1.pdf

**Table 5.1 — Traffic zones inside buildings**

| Ref. no. | Type of area, task or activity | $\bar{E}_m$ lx | $UGR_L$ – | $U_o$ – | $R_a$ – | Specific requirements |
|---|---|---|---|---|---|---|
| 5.1.1 | Circulation areas and corridors | 100 | 28 | 0,40 | 40 | • Illuminance at floor level.<br>• $R_a$ and UGR similar to adjacent areas.<br>• 150 lx if there are vehicles on the route.<br>• The lighting of exits and entrances shall provide a transition zone to avoid sudden changes in illuminance between inside and outside by day or night.<br>• Care should be taken to avoid glare to drivers and pedestrians |
| 5.1.2 | Stairs, escalators, travolators | 100 | 25 | 0,40 | 40 | Requires enhanced contrast on the steps |
| 5.1.3 | Elevators, lifts | 100 | 25 | 0,40 | 40 | Light level in front of the lift should be at least $\bar{E}_m$ = 200 lx |
| 5.1.4 | Loading ramps/bays | 150 | 25 | 0,40 | 40 | |

*Figure 1-17: Example of lighting requirements from EN 12464-1 for traffic zones inside buildings*

The illuminance of the immediate surrounding area shall be related to the illuminance of the task area and should provide a well-balanced luminance distribution in the visual field. The immediate surrounding area should be a band with a width of at least 0.5 m around the task area within the visual field. The minimum illumination requirements for this area are lower (Figure 1-18).

| Illuminance on the task area $E_{task}$ lx | Illuminance on immediate surrounding areas lx |
|---|---|
| ≥ 750 | 500 |
| 500 | 300 |
| 300 | 200 |
| 200 | 150 |
| 150 | $E_{task}$ |
| 100 | $E_{task}$ |
| ≤ 50 | $E_{task}$ |

*Figure 1-18: Relationship of illuminances on immediate surroundings to the illuminance on the task area*

Illuminance on the background area, it should be a border at least 3 m wide adjacent to the immediate surrounding area within the limits of the space and shall be illuminated with a maintained illuminance of 1/3 of the value of the immediate surrounding area.

Section '4.2.2 Reflectance of surfaces' specifies that the recommended reflectances for the major interior diffuse surfaces are:

ceiling: 0.7 to 0.9;
walls: 0.5 to 0.8;
floor: 0.2 to 0.4.

Note: the reflectance of major objects (like furniture, machinery, etc.) should be in the range of 0.2 to 0.7.

Note: the revision process of this standard has recently started. Gaps will be communicated directly to the convenor and the section hereafter will be updated accordingly.

Potential gaps in EN 12464-1:

- Reference could be made to EN 15232 and that task areas and their surrounding areas can change over the life time of a building, therefore a building management system could flexibly reconfigure the illumination levels and provide additional savings. It is unclear if and how these savings are modelled. Areas where frequent changes can be expected over the building life time could be identified (e.g. open plan office) and recommendations for building management systems could be included.
- No specific 'short measurement' verification method is included. Section 4.4 defines the illumination grid that is used for calculation, but this would require a large number of measurements per room.
- In relation to the previous gaps the following comment from the lighting designers association IALD[23] is relevant based on their experience from applying this standard in the field:
  - All illuminances are a result of calculations based on recommended reflectances (section 4.2.2).
  - Architects and interior designers are not required to meet these requirements. The effect of lighting measured in illuminance will vary therefore according to the reflectances of surfaces with the result that the illuminances in the standard can be either too low or too high to meet the visual requirements of the workplace or other space.
  - In respect of good design practice, reconfigurable spaces should be designed with fixed lighting that meets the requirements for the background area or immediately surrounding area depending on the size and nature of the space with task lighting provided separately related to furnishing. This would reduce the practice of over lighting entire floor plates to task level and result in very considerable energy savings.

**EN 12464-2: *'Light and Lighting-Part 2: Lighting of outdoor work places.'***

Scope:

EN 12464-2 focuses on the recommendations for outdoor work places that are used at night. It includes important recommendations on how obtrusive light can be limited, to keep our night sky free of light pollution.

This European Standard does not specify lighting requirements with respect to the safety and health of workers at work and has not been prepared in the field of application of Article 153 of the EC treaty, although the lighting requirements, as specified in this standard, usually fulfil safety needs. Lighting requirements with respect to the safety and health of workers at work may be contained in Directives based on Article 153 of the EC treaty, in national legislation of member states implementing these directives or in other national member state legislation.

To enable people to perform outdoor visual tasks efficiently and accurately, especially at night, adequate and appropriate lighting has to be provided. The degree of visibility and comfort required in a wide range of outdoor work places is governed by the type and duration of activity.

This part 2 of EN 12464 provides the lighting design criteria for 15 installation task groups and 97 task activities in terms of quantity and quality of illumination. It also defines the maintenance, energy efficiency and system verification procedures.

In addition recommendations are given for good lighting practice.
This European Standard neither provides specific solutions, nor restricts the designer's freedom from exploring new techniques nor restricts the use of innovative equipment.

**CEN/TR 13201-1: 'Road lighting - Part 1: Selection of lighting classes.'**

Scope:

This technical report specifies the lighting classes set out in EN 13201-2 and gives guidelines on the application of these classes. To do this, it includes a system to define an outdoor public traffic area in terms of parameters relevant to lighting. To assist in the application of classes, it suggests a practical relationship between the various series of lighting classes, in terms of comparable or alternative classes. It also gives guidelines on the selection of the relevant area to which the lighting classes from EN 13201-2 and the calculation grids and procedure from EN 13201-3 should be applied.

It is important to mention that this document is only a technical report, not a standard.

**EN 13201-2: 'Road lighting - Part 2: Performance requirements.'**

Scope:

This part of the European Standard defines, according to photometric requirements, lighting classes for road lighting aiming at the visual needs of road users, and it considers environmental aspects of road lighting.
Installed intensity classes for the restriction of disability glare and control of obtrusive light and installed glare index classes for the restriction of discomfort glare are defined in annex A.

**EN 13201-3: 'Road lighting - Part 3: Calculation of performance.'**

Scope:

This European Standard defines and describes the conventions and mathematical procedures to be adopted in calculating the photometric performance of road lighting installations designed in accordance with EN 13201-2.

The calculation methods described in EN 13201-3 enable road lighting quality characteristics to be calculated by agreed procedures so that results obtained from different sources will have a uniform basis.

**EN 13201-4: 'Road lighting - Part 4: Methods of measuring lighting performance.'**

Scope:

This part of the European standard specifies the procedures for making photometric and related measurements of road lighting installations, and gives advice on the use and selection of luminance meters and illuminance meters.
It aims to establish conventions and procedures for lighting measurements of road lighting installations.

The conventions for observer position and location of measurement points are those adopted in EN 13201-3. Conditions which may lead to inaccuracies are identified and precautions are given to minimize these.
A format for the presentation of measurements is also provided.

**EN 12193: 'Light and lighting - Sports lighting.'**

Scope:

This standard specifies lighting for those indoor and outdoor sports events most practised in Europe. It provides lighting values for the design and control of sports lighting installations in terms of illuminances, uniformity, glare restriction and colour properties of the light sources. All requirements are intended to be minimum requirements. It also gives methods by which these values are measured. For the limitation of glare, it also points out restrictions on the location of the luminaires for specific applications. For emergency lighting this standard refers to the requirements of EN 1838.

**EN 1838: 'Lighting applications - Emergency lighting.'**

Scope:

This standard specifies the luminous requirements for emergency lighting systems installed in premises or locations where such systems are required. It is principally applicable to locations where the public or workers have access.

**CIE 126: 'Guidelines for minimizing sky glow**

Scope:

In most countries of the world, astronomical observations are disturbed by the light from outdoor lighting installations. Part of the light is scattered in the atmosphere and forms a luminous halo. The phenomenon is called 'sky glow'. This Technical Report gives general guidance for lighting designers and policy makers on the reduction of the sky glow. The report discusses briefly the theoretical aspects of sky glow and it gives recommendations about maximum permissible values for lighting installations in relation to the needs of astronomical observations - casual sky viewing included. These values must be regarded as limiting values. Lighting designers should do all that is possible to meet the lowest specifications for the design unless the specific installation requires relaxation. Other uses of the open air areas at night will usually result in less stringent sky-glow requirements. Practical implementation of the general guidance is left to National Regulations. Other aspects of light obtrusion are covered in detail by CIE TC 5-12 "Obtrusive light".

**CIE 150: 'Guide on the Limitation of the Effects of Obtrusive Light from Outdoor Lighting Installations.'**

Scope:

The purpose of this Guide is to help formulate guidelines for assessing the environmental impacts of outdoor lighting and to give recommended limits for relevant lighting parameters to contain the obtrusive effects of outdoor lighting within tolerable levels. As the obtrusive effects of outdoor lighting are best controlled initially by appropriate design, the guidance given is primarily applicable to new installations; however, some advice is also provided on remedial measures which may be taken for existing installations.

This Guide refers to the potentially adverse effects of outdoor lighting on both natural and man-made environments for people in most aspects of daily life, from residents, sightseers, transport users to environmentalists and astronomers. (Astronomers should also see CIE 126-1997)

The daytime appearance of the lighting installation is important. The size and nature of the lighting support structures may be intrusive by day although this subject is not addressed in this Guide.

Status:

This standard is currently under revision in CIE TC 5-28.

**CIE 171 (2006): 'Test Cases for Assessment of Accuracy of Lighting Computer Programs'**

Scope:

The objective of this report is to help lighting program users and developers assess the accuracy of lighting computer programs and to identify their weaknesses. A validation approach is therefore presented based on the concept of separately testing the different aspects of light propagation. To apply this approach, a suite of test cases has been designed where each test case highlights a given aspect of the lighting simulation domain and is associated with the related reference data.

Two types of reference data are used: data based on analytical calculation and data based on experimental measurements. The first is associated with theoretical scenarios that avoid uncertainties in the reference values. The second type is obtained through experimental measurements, where the scenario and the protocol are defined in a manner that minimises the uncertainties associated with the measurements.

A set of recommendations is also presented in order to achieve reliable experimental data for validation purposes. These recommendations address the choice and description of the scenarios, to the experimental protocol precautions, to the estimation of the error sources and to the presentation of the reference data.

The report is written in English, with a short summary in French and German. It consists of 97 pages with 27 figures and 65 tables.

Notes:

This standard provides test cases but sets no limits on accuracy. It is left to the member states to determine whether they will allow the use of these calculations in their EPBD implementation. For example, Belgium uses the standard test cases and specifies accuracy limits in order to use lighting design software calculations to be included in EPBD[30].

### 1.4.2.5 Some examples of performance standards on parts of the system

**IEC 62386-101: 'Digital addressable lighting interface - Part 101: General requirements – System.'**

Scope:

IEC 62386-101:2009 specifies a protocol for control by digital signals of electronic lighting equipment using AC or DC power supplies. Part 101 is intended to be used in conjunction with Part 102, which contains general requirements for the relevant product type (control gear), and containing clauses to supplement or modify the corresponding clauses in Parts 101 and 102 in order to provide the relevant requirements for each type of product. This International Standard, together with IEC 62386-102 and IEC 62386-201, replaces Clause E.4, "Control by digital signals", and Annex G, "Test procedures".

**EN 62386-209: 'Digital addressable lighting interface - Part 209: Particular requirements for control gear - Colour control (device type 8).'**

Scope:

IEC 62386-209:2011 specifies a protocol and test procedures for the control by digital signals of electronic control gear that can change light colour. This publication contains .pdf files, which reproduce the test sequences illustrated in Figures 5 to 127. These files are intended to be used as a complement and do not form an integral part of the publication. This publication is to be read in conjunction with IEC 62386-101:2009 and IEC 62386-102:2009.

**EN 60927: 'Auxiliaries for lamps - Starting devices (other than glow starters) - Performance requirements.'**

Scope:

This International Standard specifies performance requirements for starting devices (starters and ignitors) for tubular fluorescent and other discharge lamps for use on AC power supplies up to 1 000 V at 50 Hz or 60 Hz, which produce starting pulses not greater than 5 kV. This standard is used in conjunction with IEC 61347-1 and IEC 61347-2-1.

**EN 60923: 'Auxiliaries for lamps. Ballasts for discharge lamps (excluding tubular fluorescent lamps). Performance requirements.'**

Scope:

This International Standard specifies performance requirements for ballasts, for discharge lamps such as high-pressure mercury vapour, low-pressure

[30] http://www.epbd.be/index.cfm?n01=light&n02=procedure_of_recognition&lang=fr

sodium vapour, high-pressure sodium vapour and metal halide lamps. Clauses 12 through 15 each detail specific requirements for a particular type of ballast. This standard covers inductive type ballasts for use with AC power supplies up to 1 000 V at 50 Hz to 60 Hz associated with discharge lamps, having rated wattage, dimensions and characteristics as specified in the relevant IEC lamp standards.

**EN 60927: 'Auxiliaries for lamps - Starting devices (other than glow starters) - Performance requirements.'**

Scope:

This International Standard specifies performance requirements for starting devices (starters and ignitors) for tubular fluorescent and other discharge lamps for use with AC power supplies up to 1 000 V at 50 Hz or 60 Hz, which produce starting pulses not greater than 5 kV. This standard is used in conjunction with IEC 61347-1 and IEC 61347-2-1.

**EN 60929: 'AC-supplied electronic ballasts for tubular fluorescent lamps – Performance requirements'.**

Scope:

This International Standard specifies performance requirements for electronic ballasts for use with AC power supplies up to 1 000 V at 50 Hz or 60 Hz with operating frequencies deviating from the supply frequency, associated with tubular fluorescent lamps as specified in IEC 60081 and IEC 60901 and other tubular fluorescent lamps for high frequency operation. (It only applies to electronic ballasts; ferromagnetic ballasts are covered under IEC60921.)

**EN 61167: 'Metal halide lamps - Performance specifications.'**

Scope:

This standard specifies the performance requirements for metal halide lamps for general lighting purposes.

**EN 62639: 'Fluorescent induction lamps - Performance specifications.'**

Scope:

This standard specifies the performance requirements for fluorescent induction lamps for general lighting purposes. In this standard, the term 'lamp' stands for 'induction lamp'. It may be expected that lamps which comply with this standard will start and operate satisfactorily at voltages between 92% and 106% of rated supply voltage and at an ambient air temperature between 10 °C and 50 °C, when operated with ballasts complying with IEC 60929 and IEC 61347-2-3, as far as applicable, and in a luminaire complying with IEC 60598-1.

**EN 60081: 'Double-capped fluorescent lamps - Performance specifications.'**

Scope:

Gives technical requirements for tubular fluorescent lamps with preheated cathodes for general lighting service, operated with or without a starter from AC mains. It also describes tests for lamps with non-preheated cathodes operated without the use of a starter. It gives testing methods to be used for checking quality and interchangeability for type testing, for individual lamp batches or for a manufacturer's entire production. It consists of a series of standard data sheets, each giving the characteristics of a specific lamp type. Lastly, it introduces new co-ordinates for the standard colours together with a new standard 'white' colour.

**EN 50294: 'Measurement Method of Total Input Power of Ballast-Lamp Circuits'.**

Scope:

This Standard gives the measurement method of the total input power for ballast-lamp circuits when operating with their associated fluorescent lamp(s). This standard applies to electrical ballast-lamp circuits comprised solely of the ballast and of the lamp(s). Note: requirements for testing individual ballasts during production are not included. It specifies the measurement method for the total input power for all ballasts sold for residential and normal commercial purposes operating with the following fluorescent lamps: linear lamps with power equal to or greater than 15 W; single ended (compact) lamps with power equal to or greater than 18 W; and other general purpose lamps. This standard does not apply to: ballasts which form an integral part of the lamp; ballast-lamp circuits with capacitors connected in series; controllable wire-wound magnetic ballasts; luminaires which rely on additional optical performance aspects.

### 1.4.2.6 Examples of safety standards on parts of the system

**EN 62471: 'Photobiological safety of lamps and lamp systems'**

Scope:

This standard gives guidance for evaluating the photobiological safety of lamps and lamp systems including luminaires. Specifically it specifies the exposure limits, reference measurement technique and classification scheme for the evaluation and control of photobiological hazards from all electrically powered incoherent broadband sources of optical radiation, including LEDs but excluding lasers, in the wavelength range from 200 nm through 3000 nm. This standard was prepared as Standard CIE S 009:2002 by the International Commission on Illumination.

**IEC/TR 62778: Application of IEC/EN 62471 for the assessment of blue light hazard to light sources and luminaires (Technical report)**

Scope:

IEC/TR 62778:2012 brings clarification and guidance concerning the assessment of blue light hazard of all lighting products which have their main emission in the visible spectrum (380 nm to 780 nm). By optical and spectral calculations, it is shown what the photobiological safety measurements as described in IEC/EN 62471 tell us about the product and, if this product is intended to be a component in a higher level lighting product, how this information can be transferred from the component product (e.g. the LED package, the LED module, or the lamp) to the higher level lighting product (e.g., the luminaire).

**EN 62035:** ***'Discharge Lamps (Excluding Fluorescent Lamps) - Safety Specifications'.***

Scope:

Specifies the safety requirements for discharge lamps (excluding fluorescent lamps) for general lighting purposes.

This International Standard is applicable to low-pressure sodium vapour lamps and to high-intensity discharge (HID) lamps, i.e. high-pressure mercury vapour lamps (including blended lamps), high-pressure sodium vapour lamps and metal halide lamps. It applies to single- and double-capped lamps.

**EN 60968: 'Self-ballasted lamps for general lighting services - Safety requirements.'**

Scope:

This International Standard specifies the safety and interchangeability requirements, together with the test methods and conditions, required to show compliance of tubular fluorescent and other gas-discharge lamps with integrated means for controlling starting and stable operation (self-ballasted lamps), intended for domestic and similar general lighting purposes, having: - a rated wattage up to 60 W; - a rated voltage of 100 V to 250 V; - Edison screw or bayonet caps. The requirements of this standard relate only to type testing. Recommendations for whole product testing or batch testing are under consideration. This part of the standard covers photobiological safety according to IEC 62471 and IEC/TR 62471-2.

**EN 62035: 'Discharge lamps (excluding fluorescent lamps) - Safety specifications.'**

Scope:

Specifies the safety requirements for discharge lamps (excluding fluorescent lamps) for general lighting purposes. This International Standard is applicable to low-pressure sodium vapour lamps and to high-intensity discharge (HID) lamps, i.e. high-pressure mercury vapour lamps (including blended lamps), high-pressure sodium vapour lamps and metal halide lamps. It applies to single- and double-capped lamps.

**EN 62532: 'Fluorescent induction lamps - Safety specifications.'**

Scope:

This standard specifies the safety requirements for fluorescent induction lamps for general lighting purposes. It also specifies the method a manufacturer should use to show compliance with the requirements of this standard on the basis of whole production appraisal in association with his test records on finished products. This method can also be applied for certification purposes. Details of a batch test procedure, which can be used to make limited assessment of batches, are also given in this standard.

Besides these European and CEI or ISO standards, countries can have own standards and/or legislation.

E.g. on the ergonomic aspects on the workplace, the Netherlands have a standard 'NEN 3087 Ergonomie' that discusses visual ergonomics in relation to lighting and

Belgium has a law 'Codex for well-being on the workplace' that also threats ergonomics and lighting.

**A full list of European standards is in Annex A.**

### 1.4.3 US standards and building codes[31]

Building energy performance codes in the USA are mostly adopted at state level. There are different codes in place in different states as indicated in Figure 1-15. Essentially the codes adopted are aligned with different generations of the ASHRAE 90.1 or IECC[32] model building codes.

#### *1.4.3.1 Indoor lighting controls requirements*

The ASHRAE Standard 90.1 requires the use of automatic daylight responsive controls but only when the daylight area from side-lighting is more than 250 ft$^2$. It also requires other criteria to be met before daylighting controls are required. One such requirement is that of effective aperture. Effective aperture is a term used to characterise the relationship between the window area, its location on the perimeter wall, and its ability to daylight a space. Here again, the definition of effective aperture varies from one standard to the other.

Under the ASHRAE Standard 90.1, daylighting controls are only required in those spaces where the effective aperture is greater than 0.1 (10%). Furthermore for spaces smaller than 10,000 ft$^2$ (929 W/m$^2$), one manual control device is required for every 2,500 ft$^2$ (232 W/m$^2$). For spaces larger than 10,000 ft$^2$, one manual control device is required for every 10,000 ft$^2$.

In the ASHRAE Standard 90.1, the occupant must be able to reduce the lighting power to between 30% and 70% of full power using the manual control device. Spaces such as corridors, stairways, electrical/mechanical rooms, public lobbies, restrooms, storage rooms are exempted. Also exempted are spaces with only one luminaire with a rated power of less than 100 W and spaces with a lighting power density allowance of less than 0.6 W/ft$^2$ (6.5 W/m$^2$).

Energy codes require that all building spaces be controlled by an automatic control device that shuts off general lighting. This control device must turn off lights in response to a time-based operation schedule, occupancy sensors that detect the absence of occupants, or a signal from the building's energy management system or some other system that indicates that the space is empty. Display, accent, and case lighting must be controlled using separate control devices.

##### *1.4.3.1.1 Lighting Power Reduction Controls*

Under the ASHRAE Standard 90.1, certain exterior lighting categories must reduce, and in some cases completely turn off, lighting in response to an operation schedule or actual occupancy.

[31] Sources for this section include: *DOE Updates National Reference Standard for Commercial Buildings to 90.1-2013*, Lighting Controls Association, November 3, 2014 and *What's New in ASHRAE/IES 90.1-2013*, DiLouie C., September 22, 2014 both at http://lightingcontrolsassociation.org/lca/topics/energy-codes/
And *Lighting Development, Adoption, and Compliance Guide*, Building Technologies Program, September 2012, Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830 | PNNL-SA-90653

[32] E.g. ANSI/ASHRAE/IES 90.1-2010. *2010 Energy Conservation in New Buildings Except Low Rise and Residential Buildings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia, and IECC. 2012. *International Energy Conservation Code*. International Code Council, Washington D.C

The following controls are required by the ASHRAE Standard 90.1:

- Building façade and landscape lighting is required to be shut off between midnight or business closing, whichever is later, and 6 a.m. or business opening, whichever is earlier.
- All other lighting must be reduced by at least 30% of full power using either occupancy sensors to turn lights off within 15 minutes of sensing zero occupancy, or from midnight or one hour from close of business, whichever is later, until 6 a.m. or business opening, whichever is earlier.

Exterior lighting provided for security, safety, or eye adaptation, such as covered parking lot or building entrances and exits, is exempted from lighting reduction control requirements.

As a complement to the ASHRAE 90.1 and IECC codes the Illuminating Engineering Society of North America and the US Lighting Controls Association have published the LEM-7 Guide to Energy-Saving Lighting Controls[33]. This is a detailed guide to energy-saving lighting controls and is intended to help designers, users, commissioning agents and other interested parties understand energy-saving strategies, design considerations, equipment, the variety of communication protocols and the importance of commissioning for lighting control systems installed in both interior and exterior applications in all types of buildings.

#### 1.4.3.2 Outdoor lighting control requirements

The ASHRAE/IES 90.1-2010, standard, requires all outdoor lighting be controlled by a photo-sensor. Building façade and landscape lighting must be controlled by a time switch that turns the lights off at some point during the night.

The energy standard also requires all outdoor lighting power—other than building façade and landscape lighting, but including advertising signage—to be reduced by at least 30% after normal business operations based on a schedule or occupancy.

Parking garage lighting power must be reduced by at least 30% based on occupancy, with control zones limited to 3,600 $ft^2$ ($335m^2$). Daylight harvesting and separate control for daylight transition areas (i.e. entrances and exits) must be implemented.

#### 1.4.3.3 Interior Lighting Power Density Limits

The interior lighting power density (LPD) limits are presented by the ASHRAE or IECC energy codes as either whole building (building area) or space-by-space requirements, or both. For whole-building compliance, the total lighting power designed for the building must be no greater than the allowed LPD for the building type. For space-by-space, the total power designed for the building must be no greater than the sum of the individual space allowances multiplied by the area of that space type in the building.

The LPD limits are based on a set of space-type lighting models that mimic quality energy efficient design for that space type. These models incorporate all primary elements involved in design, including current product lamp efficacy, luminaire efficiency, light loss factors, and common design practice. Values are developed for most expected types of building space such that reasonably efficient designs can be accomplished. It is recognised that in some applications, the configuration of an individual space or specific lighting needs may make it difficult to meet the allowance for that space. Therefore, most interior space-by-space LPD compliance is based on a

[33] See http://lightingcontrolsassociation.org/lca/topics/energy-codes/

total building trade-off principle. This means that the summed allowance for the entire building can be used anywhere in the building.

#### *1.4.3.4 The 2013 ASHRAE 90.1 national energy reference standard*

The latest version of the ASHRAE 90.1 code is the ASHRAE/IES 90.1-2013 standard. On September 26, 2014, the U.S. Department of Energy (DOE) named the ASHRAE/IES 90.1-2013 energy standard as the new national energy reference standard, superseding the 2010 version in effect until then. As a result within two years, all states in the United States must put into effect a commercial building energy code at least as stringent as the 2013 version of 90.1, or justify why they cannot comply.

The ASHRAE/IES Standard 90.1 provides a model commercial building energy code that can be adopted by states and other jurisdictions. The standard, which applies to new construction and major renovations (including requirements for lamp-ballast retrofits), is updated every three years. The lighting section of ASHRAE/IES 90.1 has become increasingly sophisticated over the past 14 years, particularly in regard to lighting controls. The 2013 standard attempts to go even further while simplifying understanding and application.

The major changes to ASHRAE/IES 90.1 2013's Section 9 on lighting include:

- adjustments to the maximum permitted lighting power densities (LPD)
- more stringent lighting control requirements
- a new table format for determining lighting power and control requirements in individual spaces

There are two routes by which LPD values are specified: the space by space method or the building area method. The Building Area Method specifies maximum permitted LPD values for the whole building depending on the building type, while the space by space method specifies maximum permitted LPD values for specific types of building space e.g. offices, corridors, toilet blocks etc. Compliance with the code allows either approach to be used as long as a decision is made to use one or the other for the whole site in question.

The latest LPD values derived using the "Building Area Method" can be summarised as follows:

- hospitals - 1.05 W/ft2 (11.3 W/m²)
- offices - 1.01 W/ft2 (10.9 W/m²)
- retail - 0.9 W/ft2 (9.7 W/m²)
- schools/universities - 1.05 W/ft2 (11.3 W/m²)
- warehouse buildings – 1.01 W/ft2 (10.9 W/m²)

These adjustments save power where possible according to new light level recommendations published by the Illuminating Engineering Society (IES) of North America.

The primary change in ASHRAE/IES 90.1-2013 is a new table (Table 9.6.1) format for determining the LPD allowances using the space by space method and minimum mandatory control requirements using either the space by space method or building area method. The table was developed to simplify reading and reference of LPD and control requirements in each space, but, at first glance, it may appear confusing. One must read the accompanying text as separate requirements and options applicable to the table, not a consecutive list of actual requirements. Otherwise, proper use of the table is in the fine print. For example, two tables actually list space types, but the first represents space types commonly found in multiple building types, while the second covers space types typically found in a single building type.

For open offices, the LPD is 0.98 $W/ft^2$ if using the space by space method. The room cavity ratio (RCR) threshold is 4, meaning an additional lighting power allowance of 20 percent is available if the actual RCR (2.5 × room cavity height × room perimeter length ÷ room area) exceeds the threshold. Various controls are then required, and some choices are available. For example, in open offices, space controls are required to give users control over their lighting. All lighting must be capable of bi-level control. If daylight is present, lighting in the daylight zones must be separately and automatically controlled. The lights may be manual-on or partial-automatic-on, and they must be turned off automatically based on occupancy or a schedule. The requirements for lighting controls in the 2013 version of the ASHRAE standard include that:

- Occupancy sensors must be set to turn the lights off within 20 minutes (instead of 30 minutes) after a space is vacated.
- Automatic independent control should be installed in secondary side-lit daylight zones (covering additional luminaires farther from the windows) rather than just receiving an incentive via a control credit.
- Daylight harvesting step-dimming control now requires two control points between off and full-on—one dim level between 50–70 percent of design power and one between 20–40 percent—to provide greater flexibility.
- A second automatic lighting shutoff option is required for certain occupancy sensor installations—partial-off to 50 percent of design power within 20 minutes of the space being vacated—spaces where the lights are periodically not needed but must remain on.
- More detailed functional testing requirements are imposed.

#### 1.4.3.5 Status of adoption by US State

The generations of codes adopted at state level as of August 2014 can be classified as being one of the following:

- No state level code adopted
- ASHRAE 90.1-2001 or IECC 2003 equivalent or more energy efficient
- ASHRAE 90.1-2004 or IECC 2006 equivalent or more energy efficient
- ASHRAE 90.1-2007 or IECC 2009 equivalent or more energy efficient
- ASHRAE 90.1-2010 or IECC 2012 equivalent or more energy efficient

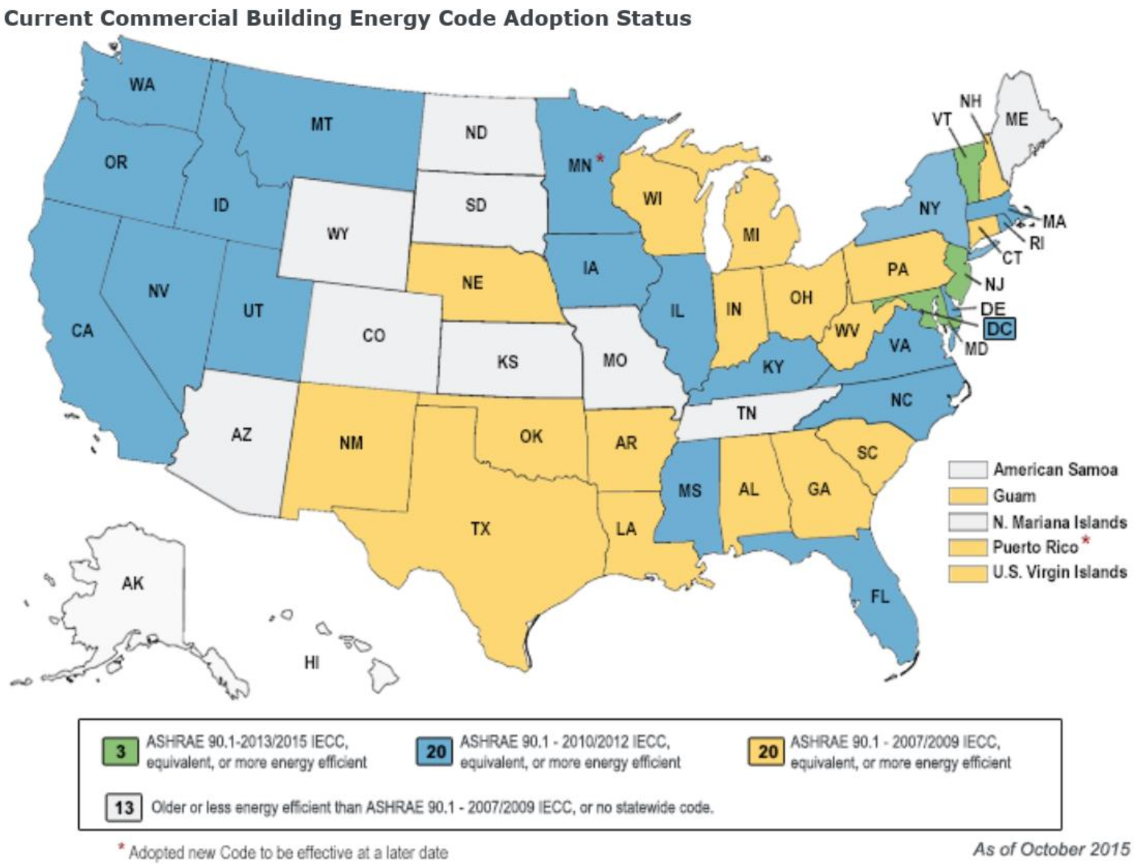


*Figure 1-19: The status of building energy codes adopted for commercial buildings in US states*

Source: https://www.energycodes.gov/status-state-energy-code-adoption

Where the later the vintage of the ASHRAE 90.1 or IECC code adopted the more demanding are the energy efficiency specifications.

### 1.4.4 Analysis and reporting on new test standards, problems and differences covering the same subject

As already stated in the description of EN 15193 this standard seems to be too complicated for the users. This results in different and country dependent standards or legislation implementing the Energy Performance of Buildings Directive.

The current situation (1/2015) in many EU Member States is that they only use parts of European standards illustrated in Figure 1-20. Some Member States (e.g. D & AT) develop a local standard (see 1.4.2) such as DIN 18599-4 (D, LU) or ÖNORM H 5059 (AT) while others implement the EN standards directly into their local legislation (e.g. BE & FR) (see 1.5.1.6).

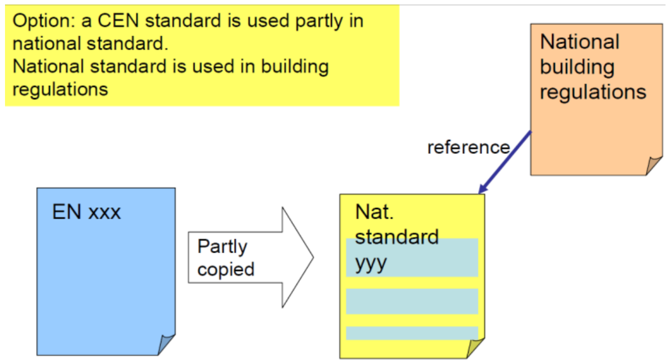


*Figure 1-20: Actual situation in many EU Member States regarding how they use the EPBD standards*[34]

### 1.4.5 Ongoing standardisation mandates from the European commission

#### 1.4.5.1 Introduction to mandates from the European Commission

Mandates are the mechanism by which the European Commission (EC) and the secretariat of the European Free Trade Association (EFTA) request the European Standardization Organizations (ESOs) to develop and adopt European standards in support of European policies and legislation.

#### 1.4.5.2 Mandate M/480 - EPBD

M/480 Mandate to CEN, CENELEC and ETSI for the elaboration and adoption of standards for a methodology calculating the integrated energy performance of buildings and promoting the energy efficiency of buildings, in accordance with the terms set in the recast of the Directive on the energy performance of buildings (2010/31/EU)[35].

#### 1.4.5.3 Mandate M/495 – Ecodesign horizontal mandate

The request from the Commission (EC mandate M/495) is a horizontal mandate covering more than 25 different types of products that use energy or have an impact on the use of energy. Types of products covered by this mandate include: air conditioning and ventilation systems, boilers, coffee machines, refrigeration units, ovens, hobs and grills, lamps and luminaries, tumble dryers, heating products, computers and monitors, washing machines, dryers and dishwashers, sound and imaging equipment, water heaters, etc.

Standardisation needs defined in its annexes related to tertiary and office lighting were:

- standby and off mode power
- luminaire efficiency
- FL ballast efficiency (amend EN 50294)
- HID ballast efficiency measurement method

Technical Committee(s) concerned with M/495 include: CIE, IEC TC34 and SCs, CLC TC 34Z /IEC TC 34C.

#### 1.4.5.4 M/485 Mandate in the field of fluorescent lamps, high-intensity discharge lamps, ballasts and luminaires able to operate such lamps

This specific mandate is related to M/495, which is the horizontal mandate.

[34] Source: CENSE project workshop presentation 'Standardisation work on EPBD CEN- standards towards better energy performance of buildings and their further development in CEN & ISO' (23/3/201).
[35] https://www.cen.eu/work/supportLegislation/Mandates/Pages/default.aspx

The mandate requires the development of procedures and methods of measuring the following product parameters:

- For fluorescent and high-intensity discharge lamps, the spectral radiation, the luminous flux, the power consumption, the lamp lumen maintenance factor, the lamp survival factor, the chromaticity, the correlated colour temperature, the colour rendering, the specific effective radiant ultraviolet power, the lamp caps and the total mercury content;
- For ballasts able to operate fluorescent and high-intensity discharge lamps, the *input power* of the lamp-ballast circuit*, including when the operated lamps do not emit any light in normal operating conditions*;
- For luminaires able to operate fluorescent and high-intensity discharge lamps*, the power consumption when the operated lamps do not emit any light in normal operating conditions*, the ingress protection grading, *the CEN flux code and the photometric file*;
- For luminaires for office lighting*, the luminaire maintenance factor*;
- For luminaires for street lighting, *the luminaire maintenance factor*, *the utilisation factor* and the Upward Light Output Ratio.

*Text in italic is of particular interest to the lighting system study.*

### 1.4.6 Conclusions and summary of standards

#### *1.4.6.1 What are the relevant new and updated standards and is there a missing standard or overlap?*

First, it is important to conclude that for all the primary and secondary lighting system functional parameters described in 1.3.3 that standards are available to define and measure them. Therefore, there are no clearly missing standardisation needs at the moment. The deficiencies which have been identified in the standards are mainly concerned with the need to improve accuracy, increase user acceptance and/or provide better coverage of new technologies such as LEDs or controls.

The standards do not overlap in principle apart from EN 15193 that is implemented differently across the Member States, as explained below. It should be noted that within standardisation some acronyms and terminology has changed over time. For example Lumen Maintenance Factor is denoted as LMF in CIE 97(2007) yet is denoted as FLM in EN 12665(2011), but these are problems that will be solved in the normal standardisation update and revision cycles. It is also worth noting that LED light sources have various other life time and lumen maintenance parameters (LxFy) that need to be converted[36] into the maintenance factor(FM) and lamp survival factor (FLS) as used for fluorescent and high intensity lamps and their luminaires. At the moment a guideline[36] is available to address this but it is also expected that this will be included in a European Standard. Hence, for this reason it is not recognised as a missing item within this study.

The European standard for indoor lighting EN 15193 (2007): 'Energy performance of buildings – Energy requirements for lighting' has had limited acceptance so-far within the Member States, see 1.4.2.2, and as a result the standard has only been implemented partially or subject to local variants (e.g. DIN 18599, see 1.4.2.3). However this standard is currently under review and will hopefully have broader acceptance in the future. The current draft proposal now also includes a means of decomposing the system based on so-called expenditure factors that are very similar to the system decomposition expressed in Figure 1-3 within this study. The main

[36] ZVEI (2013): 'Guide to Reliable Planning with LED Lighting Terminology, Definitions and Measurement Methods: Bases for Comparison'

purpose is to give the user better insight in which system elements are most likely to provide efficiency gains.

A similar standard for road lighting is under development, prEN 13201-5: 'Road lighting-Part 5: Energy performance indicators'. This standard is similar to EN15193 on indoor lighting but uses other acronyms and terminology. The study follows also this draft standard in the extend possible, see

#### *1.4.6.2 Are there possible problems with standards for later policy measures?*

Yes, verifying the minimum maintained illuminance and surface reflection coefficients could be a complicated task as reported in EN 12464 in section 1.4.2.4 and the discussion on potential gaps herein.

It has also been reported that the ceiling/wall/floor reflectance has an important impact on the outcomes.

#### *1.4.6.3 Are there draft outlines for possible European Mandates to ESOs?*

As no missing standards were identified in 1.4.6.1, at this stage the only recommendations are to update CIE 97 and CIE 151 (see 1.4.2) with respect to the Luminaire Maintenance Factor (FLM); however, it has been reported that a review is already planned for this standard. This statement can be reviewed in later Task 7 when discussing the policy measures.

## 1.5 Overview and description of legislation

**Scope**:
According to the MEErP the aim of this task is to identify and shortly describe the relevance for the product scope of:

- EU legislation (legislation on resources use and environmental impact, EU voluntary agreements, labels)
- Member State legislation (as above, but for legislation indicated as relevant by Member States), including a comparative analysis)
- Third country legislation (as above, but for third country legislation), including a comparative analysis

### 1.5.1 EU legislation

#### *1.5.1.1 Introduction and overview of EU Directives related to energy efficiency of lighting*

There are four EU Directives that could influence the energy efficiency of lighting systems:

- The Energy related Products Directive (ErP)
- The Energy Labelling Directive (ELD)
- The Energy Performance in Buildings Directive (EPBD)
- The Energy Efficiency Directive (EED)

Implementing regulations within the ErP and ELD are currently applied to light sources, ballasts and luminaires. They are not currently applied to controls and do not address daylight harvesting directly. Furthermore the existing regulations only partially addresses luminaire efficiency in that they are not applied to all types and only specify information requirements.

**Note: In parallel with this study a study specifically on light sources which should be consulted for more product related information, see http://ecodesign-lightsources.eu/**

The EPBD theoretically applies to lighting systems as lighting energy performance is one of the measures that needs to be included when assessing compliance with building energy codes and when applying the cost optimal methodology to determine the cost-optimal requirements for a building energy code. Most MS simply include lighting within the overall building energy performance assessment and associated requirements, i.e. they do not set out specific performance provisions for lighting. Only a few MS set specific energy performance requirements for lighting systems in addition to setting whole building energy performance requirements. Lighting is treated within building Energy Performance Certificates (EPCs) in a similar way – i.e. its energy performance contributes to the overall rating but there are no specific requirements for or ratings of the lighting system.

If lighting is already incorporated within the whole building energy requirement why does it matter if there are no specific additional requirements? Lighting is the domain of the electrical contractors and/or lighting designers (for higher-end installations). In the absence of specific lighting energy requirements within the codes, the building project manager would need to be fully aware of the contribution that lighting makes to the whole building project's energy rating and of the potential to reduce it through efficient designs if they are to successfully manage the sub-contractors that will design and install the lighting system. It can be argued that having additional and specific minimum legal requirements for lighting system energy performance provides extra assurance that the energy performance of this system will be acceptable even in cases where the overall project procurers and managers are unaware of the opportunities it can make to the whole project performance.

The Energy Efficiency Directive (EED) also has numerous articles which could theoretically be implemented in a manner that would support lighting system efficiency, however, none of them explicitly mention lighting. Thus unless MS's decide to make dedicated provisions for lighting efficiency in their implementation of the provisions there is unlikely to be anything more than indirect support to lighting system efficiency improvement.

Articles within the EED that could provide indirect support to lighting system efficiency include:

- Article 4 – Building Renovations
- Article 7. Utility energy efficiency obligations
- Article 8 – Energy Audits
- Article 16 – Availability of qualification, accreditation and certification schemes
- Article 19 MS shall evaluate and remove barriers to EE
- Article 20. Energy Efficiency National Funds

Table 1-2 gives a summary of current EU policy instruments as they are and could be applied to lighting systems (LS) and building automated control systems (BACS).

*Table 1-2: Summary of current EU policy instruments as they are and could be applied to lighting systems (LS) and building automation and control systems (BACS)*

| **Directive** | **Measure** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **EPBD** | **Building Energy Performance Codes** | | | | | **EPCs** | | **Incentives (Article 10(2))** |
| Scope | New build | Existing buildings | Residential | Non-residential | Cost optimal assessment (Article 5) | Residential | Non-residential | All buildings |
| Status | In most MS codes the LS is not treated in a prescriptive manner but only indirectly.<br><br>BACS mostly not treated explicitly. | In most MS codes the LS is not treated in a prescriptive manner but only indirectly.<br><br>Mixed, BACS mostly not treated explicitly. | In most MS codes the LS is not treated in a prescriptive manner but only indirectly.<br><br>Mixed, BACS mostly not treated explicitly. | In most MS codes the LS is not treated in a prescriptive manner but only indirectly.<br><br>Mixed, BACS mostly not treated explicitly. | LS are included.<br><br>BACS are mostly not assessed explicitly, if at all. | LS are part of whole building rating.<br><br>No evidence any MS has considered applying this article to BACS explicitly. | LS are part of whole building rating.<br><br>No evidence any MS has considered applying this article to BACS explicitly. | No evidence any MS has considered applying this article to LS or BACS explicitly. |
| **ECODESIGN/LABELLING** | **MEPS** | **Classification/ Labelling** | **Other requirements** | | | | | |
| Status | LS being considered in Lot 37.<br><br>Household lamps in regulations 244/2009, 859/2009 and 874/2012. Directional lighting in regulations 1194/2012 and 874/2012<br><br>Tertiary sector lamps and ballasts in regulation 245/2009 and 347/2010 | LS being considered in Lot 37.<br><br>Household lamps in regulations 244/2009, 859/2009 and 874/2012. Directional lighting in regulations 1194/2012 and 874/2012<br><br>Tertiary sector lamps and ballasts in regulation 245/2009 and 347/2010<br><br>Light sources being considered in Lot | LS in Lot 37,<br><br>BACS under consideration for possible inclusion in work plan | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Light sources being considered in Lot 8/9/19.<br><br>BACS under consideration for possible inclusion in work plan | 8/9/19.<br><br>BACS under consideration for possible inclusion in work plan | | | | | |
| **EED** | **Article 7. Utility energy efficiency obligations** | **Article 20. Energy Efficiency National Funds** | **Article 4 – Building Renovations** | **Article 8 – Energy Audits** | **Article 16 – Availability of qualification, accreditation and certification schemes** | **Article 19 MS shall evaluate and remove barriers to EE** | |
| Status | Mixed/weak implementation. Not all MS have them. Many EEOs (almost all) are not yet designed to apply to LS or BACS | Mixed/weak implementation. Not all MS have them. Many funds (most) are additional and are not yet designed to apply to LS or BACS | Indirect effect on LS and BACS | Could be applied to LS and BACS but no evidence any MS has considered applying this article to them | No evidence any MS has considered applying this article to LS or BACS explicitly | No evidence any MS has considered applying this article to LS or BACS explicitly | |

Key: BACS = Building Automated Control System

EED = Energy Efficiency Directive

EPBD = Energy Performance in Buildings Directive

EPC = energy performance certificate (for buildings)

LS = lighting system

MS = Member State

Overall it is clear that the existing EU policy framework contains plenty of levers and opportunities that could be applied to the promotion of energy efficient lighting systems; however, that the application of these is variable and generally not targeted at lighting systems per se. European building energy performance codes all include the impact of the lighting system but relatively few have specific targeted requirements for lighting systems – most simply include lighting as an input into the overall building energy target. Building EPCs include lighting within the rating system but only some give specific targeted advice on the performance of the lighting system relative to its potential performance. The situation for building automated controls (which can be used to reduce lighting energy wastage) is similar except that they have even less requirements specified.

The EED includes several general provisions that could be applied in ways that would have an influence on lighting system energy efficiency but that is entirely dependent on how the measures are actually put into effect at MS level. Provisions such as the utility energy efficiency obligations, national energy efficiency funds, energy audits, building renovations and certification and accreditation measures could all in principle be applied in ways that promoted energy savings in lighting systems but there is little evidence that this has been done so far.

#### 1.5.1.2 Ecodesign requirements for non-directional household lamps

**Commission Regulation (EC) No 244/2009**
**Commission Regulation (EC) No 859/2009** (amendment)

Commission Regulation (EC) No 244/2009, implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for non-directional household lamps (hereafter 'the Regulation') was published on the 18$^{th}$ of March 2009 and entered into force two weeks later.

In Article 3 the Regulation sets requirements for Non-Directional Light Sources (NDLS), specified in Annex II of the Regulation, in 6 stages.

The first four stages, with requirements applying from the 1$^{st}$ of September 2009, 2010, 2011 and 2012, eliminate low-efficacy ('incandescent') lamps in subsequently lower lumen output-levels[37]. At the moment all general purpose incandescent lamps with output >60 lm should have been phased-out from the EU market.
Stage 1 also sets minimum functionality requirements for Compact Fluorescent Lamps (CFLs) and –in one group– light sources that are neither CFLs nor Light Emitting Diodes (LEDs). This latter group of non-CFL/LED lamps mainly includes the NDLS halogen lamps. Stage 5, which applies from 1 September 2013, sets more stringent minimum functionality requirements regarding minimum rated lamp lifetime/lamp survival factor at 6000h, lumen maintenance, number of switching cycles, starting time, heat-up time to reach 60% of lumen output, premature failure rate, UVA+UVB radiation, UVC radiation, lamp power factor (LPF) and –for CFLs only– the colour rendering index ($R_a$). Most significantly, with respect to stage 1, stage 5 tightens the requirements for the service life and lifetime functionality.

Stage 6 is applicable from 1 September 2016. It sets more stringent efficacy requirements for clear lamps, but requirements and timing of Stage 6 are currently

[37] 'low-efficacy' intended here for lamps where the rated power P exceeds the maximum rated power Pmax (in W) at a given rated luminous flux (Φ, in lm) with for non-clear lamps $P_{max}=0.24\sqrt{\Phi}+0.0103\Phi$ and for clear lamps in stages 1 to 5 $P_{max}=0.8\cdot(0.88\sqrt{\Phi}+0.049\Phi)$.

revisited by the Commission in a separate context[38]. As it stands today, Stage 6 requires that instead of the maximum rated power $P_{max}$ (in W) being $0.8\cdot(0.88\sqrt{\Phi}+0.049\Phi)$, where Φ is the rated luminous output (in lm), the rated power of clear lamps will then have to be less than a $P_{max}$ of $0.6\cdot(0.88\sqrt{\Phi}+0.049\Phi)$. Futhermore, due to differences in permitted tolerances the eco-design and energy labelling Directive specifications are no longer easily comparable.

There are a number of exemptions in the product scope of the regulation. The exemptions include not only the 'special purpose lamps', but also coloured (not 'white') lamps, directional light sources (DLS), commercial lamps that are covered by other legislation (LFLs, High Intensity Discharge HID lamps and non-integrated CFLs), lamps with lumen output below 60 or above 12000 lumen, low voltage incandescent lamps with E14/E27/B22/B15 caps. The exceptions to stage 6 requirements are clear lamps with type G9 and R7s cap. (VHK, 2013)

#### 1.5.1.3 Ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps and for ballast and luminaires able to operate such lamps

**Commission Regulation (EC) No 245/2009**
**Commission Regulation (EC) No 347/2010** (amendment)

Commission Regulation (EC) No 245/2009, implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires, was published the 18th of March 2009 and entered into force two weeks later. Commission Regulation (EC) No 347/2010 is amending Commission Regulation (EC) No 245/2009 (hereafter 'the Regulation').

The scope is defined in Article 1 and Annex 1 of the regulation. In Article 3 the Regulation sets Ecodesign requirements that are specified in Annex III of the Regulation, in 3 stages with an intermediate stage.

The possible phasing out is based upon achieving performance criteria like:

- colour rendering (Ra)
- efficacy (lm/W)
- lamp lumen maintenance factor
- lamp survival factor

For HID lamps only the lamps that have an E27, E40 or PGZ cap are within the scope of the directive.

In the first stage (2010):

- Halophosphate Fluorescent Lamps (T8 linear, U shaped, T9 circular, T4 linear) were phased out;
    - Standby losses less or equal to 1 W per ballast;
    - Fluorescent ballasts for current lamps in the market shall fulfil at least EEI = B2;
    - The term ballast efficiency was introduced;
    - Also several information requirements were introduced such as for fluorescent lamps the rated lamp efficacy at 25°C and 35°C(T5) at 50 Hz (where applicable) and at High Frequency;
    - Extract on lamp efficacy requirement:
      - LFL T8-36 W requires 93 lm/W (25°C);

[38] VHK, Review study on the stage 6 requirements of Commission Regulation (EC) No 244/2009, draft report for the European Commission, April 2013.

        - LFL T5-28 W requires 93 lm/W (25°C);
        - LFL T5-39 W requires 73 lm/W (25°C);
    - Extract on fluorescent ballast efficiency requirement:
        - T8-36 W class B2 ≥ 79.3 %;
        - T8-36 W class A2 ≥ 88.9 %;
- Table 17 on ballasts for fluorescent lamps contains rated/typical wattage for 50 Hz and HF operation. This also reflects the typical efficacy gain found for HF operation compared to 50 Hz, e.g. for the same lumen output a T8 '36 Watt' lamp needs typically 36 W at 50 Hz and 32 W at HF. HF power supply can only be provided with electronic ballasts.

In the second stage (2012):

- Halophosphate Fluorescent Lamps ( T10, T12) were phased out;
- For High Pressure Sodium and HPS / Metal Halide MH Lamps (E27/E40/PGZ12):
    - Set up established performance criteria for MH E27/E40/PGZ12 lamps;
    - Standard HPS E27/E40/PGZ12 were phased out, this means that HPS lamps need an enhanced Xenon;
- Extract on lamp efficacy requirement:
    - HPS 70 W clear ≥ 90 lm/W;
    - HPS 70 W not clear lamp ≥ 80 lm/W;
    - MH 70 W clear ≥ 80 lm/W;
    - MH 70 W not clear lamp ≥ 70 lm/W ;
- Standby losses less or equal to 0.5 W per fluorescent ballast;
- Minimum efficiency for HID ballast, e.g. a 70 W HID lamp requires 75 % efficiency;
- Introduction of minimum HID ballast efficiency and the obligation to make them available.

In an intermediate stage (2015) the following lamps:

- High pressure mercury lamps are expected to be phased out;
- High Pressure Sodium-Plug-in/Retrofit lamps (HPM replacement) are expected to be phase out;
- Extract on lamp efficacy requirement: other HID 50W ≥50lm/W

Note: The regulation 244/2009 (TBC) on household lamps is much stronger for CFLi lamps, e.g. a 50 W requires about 64 lm/W and CRI≥80 in regulation 244/2009 while any other 50 W HID requires only 50 lm/W in regulation 245/2009.

In the third stage (2017):

- Low performing MH E27/E40/PGZ12 lamps are phased out; in practice this means that 'quartz' MH lamps are phased out in favour of 'ceramic' discharge tube MH lamps;
- Compact Fluorescent Lamps with 2 pin caps and integrated starter switch (Reason: These lamps are phased out in stage 3 as they do not operate on A2 class ballasts in practice) are phased out;
- Ballasts for fluorescent lamps without integrated ballast shall have the efficiency: $\eta_{ballast} \geq EBbFL$, wherein $EBbFL = P_{lamp}/(2\cdot\sqrt{(P_{lamp}/36)}+38/36\cdot P_{lamp}+1)$ for lamps between 5 and 100 Watt.
    - For example: a 36 W T8 lamp ballast should have ηballast ≥ 87.8 %. This is far above the minimum class B1 requirement (Table 17) from stage 1 and is likely to commercially phase out magnetic ballasts in low cost applications. A side effect of phasing out magnetic fluorescent ballasts is an increase in efficacy gain for those lamps on HF operation,

as discussed later on. More efficient magnetic ballasts require more copper and are expected to become too expensive for the market.

- More strict minimum efficiency for HID ballast, e.g. 70 W HID lamp requires 85 % efficiency
  (VHK, 2013)

#### 1.5.1.4 Ecodesign requirements for directional lamps, for light emitting diode lamps and related equipment

**Commission Regulation (EC) No 1194/2012**

Commission Regulation 1194/2012 sets minimum functional requirements for directional and non- directional LED light sources. From the 1st of September 2013, minimum requirements apply for:

- the number of switches before failure (half the product life in hours, with a maximum of 15 000 switches);
- starting time (< 0.5 s);
- lamp warm-up time (<2s to reach 95 % Φ), premature failure rate (≤ 5.0 % at 1 000 h);
- colour rendering (Ra) (≥ 80, if the lamp is intended for outdoor or industrial applications[39]);
- colour consistency (maximum variation of chromaticity coordinates within a six-step MacAdam ellipse[40] or less);
- lamp power factor (PF) for lamps with integrated control gear (P ≤ 2 W: no requirement; 2 W < P ≤ 5 W: PF > 0.4; 5 W < P ≤ 25 W: PF > 0.5 ;P > 25 W: PF > 0.9)

From the 1st of March 2014 additional minimum requirements will apply on

- the lamp survival rate (>90% at 6000h[41]);
- lumen maintenance (>80% at 6000h).

#### 1.5.1.5 Energy labelling of electrical lamps and luminaires: Commission Regulation (EC) No 847/2012

A new Commission Delegated Regulation for energy labelling of luminaires and light sources was published in 2012. Contrary to the previous lamp energy label, regulated under Directive 98/11/EC, the new Regulation covers directional lamps, extra low voltage lamps, light-emitting diodes (LEDs), and lamps used predominantly in professional lighting, such as high-intensity discharge lamps. It informs consumers about the compatibility of the luminaire with energy-saving lamps and about the energy efficiency of the lamps included with the luminaire. The exclusions from the scope are similar to those intended in Regulation 244/2009. The energy efficiency limits for classes A-G are similar to the ones in Directive 98/11/EC, but new 'A+', 'A++' and 'A+++' classes have been added to accommodate more efficient lighting technology (e.g. LED). (VHK, 2013)

#### 1.5.1.6 Energy performance of buildings Directive

**Directive (2002/91/EC) and recast Directive (2010/31/EU)**

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[39] In accordance with point 3.1.3 (l) of Annex III of commission regulation 1194/2012

[40] Ellipse-shaped colour region in a chromaticity diagram where the human eye cannot see the difference with respect of the colour at the centre of the ellipse. MacAdam ellipses are used e.g. in standards for describing acceptable colour deviation between LED lamps/luminaires of the same model (1 step=1 ellipse area; 2step=2 concatenated ellipse areas, etc.)

[41] The intention is to ascertain a minimum product life (lumen maintenance >70%) of around 20 000 h. The period of 6000h at the mentioned parameters values was defined to limit costs for compliance testing.

The Energy Performance of Buildings Directive (EPBD) is, at European level, the main policy driver affecting energy use in buildings. As originally formulated in 2002, the EPBD sets out the following key requirements for Member States:

- Minimum standards on the energy performance of new buildings and large (>1000m²) existing buildings undergoing a 'major renovation';
- A general framework; for a methodology for calculating the integrated energy performance of buildings;
- Energy certification for both new and existing buildings whenever they are constructed, sold or rented out;
- Implement an inspection and assessment regime for air conditioning and boilers or, in the case of the latter, develop alternative measures to reach the same level of energy performance.

In 2010 amendments to the EPBD were finalized and published, adding several new or strengthened requirements, in particular:

- Minimum energy performance requirements for building elements that form part of the building envelope and have a significant impact on the energy performance of the building envelope once retrofitted or replaced;
- Setting up EU-wide nearly zero-energy buildings requirements and development of national plans for increasing the number of NZEB buildings;
- Abolishment of the 1000m² threshold for major renovations (now: 50m²);
- Introducing a calculation framework for calculating the cost-optimal levels of minimum energy performance requirements;
- Minimum energy performance requirements of building systems (to be applied in existing buildings and voluntarily be applied new buildings);
- Requirement of an inspection and assessment regime for air conditioning and heating systems or develop alternative measures to reach the same level of energy performance;
- Requirement of an inspection report for heating and air conditioning systems (in case of application);
- Independent control systems for EPC and inspection reports;
- Reinforcement of the energy certification of the buildings;
- Introduction of penalties.

**Certification:**

*'Member States shall ensure that an energy performance certificate is issued for (a) buildings or building units which are constructed, sold or rented out to a new tenant; and (b) buildings where a total useful floor area over 500 m 2 is occupied by a public authority and frequently visited by the public. On 9 July 2015, this threshold of 500 m² shall be lowered to 250 m². '*

Certification refers mainly to following articles of the recast EPBD[42]:

- Article 11 'Energy Performance Certificates';
- Article 12 'Issue of Energy Performance Certificates';
- Article 13 'Display of Energy Performance Certificates'.

The issuing of EPCs has an important role in the transformation of the building sector. By providing information, potential buyers and tenants can compare buildings/building

[42] Implementing the Energy Performance of Buildings Directive (EPBD) – Featuring Country Reports 2012

units. Also recommendations are provided for a cost-effective improvement, encouraging home owners to refurbish their building to a better energetic standard.

The EPBD imposes that recommendations for improving energy performance should be part of the EPC. These recommendations (standard or tailor-made) are an important communication tool for the energetic improvement potential of the building. However it should be considered that EPC recommendations cannot substitute detailed building specific energy audits. Standard recommendations for the thermal envelope will mostly depend on the U-value of the construction element. Recommendations should not only focus on an improved U-value, but also require attention to the indoor climate (CA EPBD 2010)[43].

**Cost-optimal methodology:**

*'Member States shall calculate cost-optimal levels of minimum energy performance requirements using the comparative methodology framework established in accordance with paragraph 1 of the recast EPBD and relevant parameters, such as climatic conditions and the practical accessibility of energy infrastructure, and compare the results of this calculation with the minimum energy performance requirements in force.'*

The following articles of the recast EPBD are most important for the cost-optimal methodology:

- Article 3 'Adoption of a methodology for calculating the energy performance of buildings'
- Article 4 'Setting of minimum energy performance requirements'
- Article 5 'Calculations of cost-optimal levels of minimum energy performance requirements'
- Article 6 'New buildings'
- Article 7 'Existing buildings'
- Article 8 'Technical building systems'

The cost optimal level is defined as "the energy performance level which leads to the lowest cost during the estimated economic lifecycle" (CA EPBD 2012) (Article 2.14). It is intended as a tool for Member States to see if they need to adjust their own regulations with regard to the economic optimum. Cost-optimal framework is not intended for comparisons between Member States. Member States must set national minimum energy performance requirements to achieve these cost-optimal levels. Also measures must be taken so that cost-optimal levels are achieved by new buildings or buildings undergoing a major renovation, but also for replaced or retrofitted building components that are part of the building envelope.

A framework for cost-optimal procedures is provided by the Commission Delegated Regulation (EU) No 244/2012 accompanied by Guidelines (2012/C 115/01). The Regulation is based on CEN-standards. Estimations on energy price developments on the long-term are provided by the Commission. Member States must define reference buildings (new, and existing, both residential as well as non-residential) and energy efficiency measures that are assessed for those reference buildings. Both for the reference buildings, as well as the reference buildings with the energy efficiency measures applied, final and primary energy needs are assessed and costs are calculated. Cost-optimal levels from a macroeconomic as well as from an investor's

[43] Implementing the Energy Performance of Buildings Directive (EPBD) – Featuring Country Reports 2010, '3.1.5 Processes for making recommendations'

perspective are calculated, but MS can choose on which perspective they base their energy performance requirements.

New buildings need to develop towards Nearly Zero-energy Buildings (NZEBs), but also the existing housing stock needs to be improved. Therefore requirements for existing buildings are also set in place, including building requirements as well as component requirements or combinations of both. EPBD recast states that both kinds of requirements need to be set. Requirements for components are easily comprehensible and might be adopted more easily by people planning minor renovation works. However they generally fail to take a holistic approach and are often less ambitious than whole-building requirements for major renovations[44].

The calculation of the energy performance of buildings has to be performed following a common general framework given in Annex I of the recast EPBD. The energy performance shall reflect the heating and cooling energy needs to maintain the envisaged temperature conditions of the building and domestic hot water needs (CA EPBD 2012). These heating and cooling energy needs relate to technical installations and to the building envelope and its elements and the insulation materials used in these building elements. Besides the main indicator (primary energy for most MS), U-values, thermal transmittance coefficient or transmission losses are also be used as indicators by some MS.

By the beginning of 2019 (new buildings occupied and owned by public authorities, leading the way) and 2021 (all new buildings) have to be NZEB and are supposed to also meet cost-optimal calculations. Therefore NZEB shall have a cost-optimal combination of building envelope and building service systems. Cost-optimal calculations from 2013 shall be reviewed once more before 2019/2021.

**Impacts of EPBD on lighting systems:**

The energy efficiency of lighting is explicitly addressed as a subject, mainly for the non-residential sector, in the 2010 recast of the Energy Performance of Buildings Directive (EPBD)[45]. Annex I point 3 stipulates that 'The methodology shall be laid down taking into consideration at least the following aspects: (e) built-in lighting installation (mainly in the non-residential sector);'.Annex I point 4 stipulates that 'The positive influence of the following aspects shall, where relevant in the calculation, be taken into account:.. (d) natural lighting.'.

The EPBD recast also explicitly formulates that 'Member States should use, where available and appropriate, harmonized instruments, in particular testing and calculation methods and energy efficiency classes developed under measures implementing Directive 2009/125/EC'.[46]

[44] Implementing the Energy Performance of Buildings Directive (EPBD) – Featuring Country Reports 2012, 'Energy performance requirements using the Cost-optimal methodology. Overview and Outcomes. 3.3 Requirements for existing buildings'

[45] Directive 2010/31/EU of the European Parliament and of the council fo 19 May 2010 on the energy performance of buildings. OJ L153, 18.6.2010

[46] Recital (12) of the EPBD recast.

**Examples of country implementations of the EPBD concerning lighting:**

***Belgium:***

In Belgium the EPBD is implemented at the regional level in regional decrees but the method is harmonised between the regions[47]. The decrees limit the maximum primary energy per year and per m² together with a set of other performance requirements to be calculated (relative energy level, relative insulation level, etc.). Lighting energy efficiency is taken into account in non-residential buildings[48]. Daylight control systems and presence detectors are taken into account, but the method is considerably simplified compared to EN 15193. Calculations are done on a monthly basis and do take seasonal changes in daylight into account. For presence detection the highest benefit is for manual on and automatic off implemented per area of a maximum of 30 m² (30 % saving). For daylight responsive dimming savings of up to 40 % are possible depending on the area of luminaires that are controlled together. The highest saving is for a control area of a maximum of 8 m². The method is simplified compared to EN 15193 because orientations of windows and type of shading devices are not taken into account. The calculation software to prove compliance can be downloaded free[49] .

In the Flemish region there are also specific system requirements[50] for renovated non-residential buildings.

They limit the maximum installed lighting power per m² (W/m²) depending on the task area with corrections for presence detectors, daylight control and dimming. For example the upper limit (W/m²) for an individual office with presence detectors and a daylight responsive dimmer is 15/(0.7x0.8x0.9) or 29.8 W/m² or 15 W/m² without automatic controls.

***France (RT 2012):***

The EPBD in France is regulated within local decrees[51] and limits the maximum primary energy per year and m² together with a combination of other minimum performance requirements to be calculated. Calculation software to prove compliance needs to be purchased. This software needs to be validated[52] before it is commercialised. The calculation method also takes daylight and presence detection into account.

The RT 2012 also has a set of specific requirements for lighting installations, for example:

- Public spaces in residential buildings need presence detectors (art. 27);
- Parking places need presence detectors (art. 28) (art. 40);
- Sub metering for the lighting circuit (art. 23) (art. 31);
- Light levels can be controlled in each room manual or automatic in function of presence in non-residential buildings (art. 37);
- A minimum requirement for windows area in residential buildings;

[47] Implementing the Energy Performance of Buildings Directive (EPBD) - Featuring Country Reports 2012, ISBN 978-972-8646-28-8.
[48]http://www2.vlaanderen.be/economie/energiesparen/epb/doc/BijlageEPU20130719vergunningenNA2014.pdf
[49] http://www.energiesparen.be/epb/prof/software
[50] http://www.energiesparen.be/epb/eiseninstallaties
[51] http://www.rt-batiment.fr/batiments-neufs/reglementation-thermique-2012/textes-de-references.html
[52] http://www.rt-batiment.fr/batiments-neufs/reglementation-thermique-2012/logiciels-dapplication.html

- A requirement for central lighting controllers in non-residential buildings (art. 38);
- A requirement to install presence detectors and daylight responsive detectors in non-residential buildings in common circulation areas and/or with daylight. (art. 39);
- A zoning requirement for the lighting control area to benefit maximum from daylight (art. 41).

***Germany and Luxemburg:***

These countries follow the DIN 18599-4 Standard for calculated the energy performance of lighting installations in non-residential buildings (see section 1.4.2).

***UK:***

The UK Building regulations Part L include compliance guides[53] for domestic and non-domestic buildings that specify lighting energy efficiency requirements that must be satisfied independently of the whole building performance. The requirements for domestic buildings are set out in Table 1-3.

*Table 1-3: systems continued*

| | Minimum standard | Supplementary information |
|---|---|---|
| Fixed internal lighting | a. in the areas affected by the building work provide low energy light fittings (fixed lights or lighting units) that number not less than three per four of all the light fittings in the main dwelling spaces of those areas (excluding infrequently accessed spaces used for storage, such as cupboards and wardrobes)<br>b. Low energy light fittings should have lamps with a luminous efficacy greater than 45 lamp lumens per circuit-watt and a total output greater than 400 lamp lumens<br>c. Lighting fittings whose supplied power is less than 5 circuit-watts are excluded from the overall count of the total number of light fittings | Light fittings may be either:<br>• dedicated fittings which will have separate control gear and will take only low energy lamps (e.g. pin based fluorescent or compact fluorescent lamps), or<br>• standard fittings supplied with low energy lamps with integrated control gear (e.g. bayonet or Edison screw base compact fluorescent lamps)<br><br>Light fittings with GLS tungsten filament lamps or tungsten halogen lamps would not meet the standard.<br><br>The Energy Savings Trust publication *GIL20 Low Energy Domestic Lighting* gives guidance on identifying suitable locations for fixed energy lighting.<br>A single switch should normally operate no more than six light fittings with a maximum total load of 100 circuit-watts. |

53 *Non-domestic buildings compliance guide* and *Domestic buildings compliance guide* both available at http://www.planningportal.gov.uk/buildingregulations/approveddocuments/partl/compliance

| | | |
|---|---|---|
| Fixed external lighting | Where fixed external lighting is installed, provide light fittings with the following characteristics:<br>a. Either:<br>I. lamp capacity not greater than 100 lamp-watts per light fitting, and<br>II. all lamps automatically controlled so as to switch off after the area lit by the fitting becomes unoccupied, and<br>III. all lamps automatically controlled so as to switch off when daylight is sufficient<br>b. Or:<br>I. lamp efficacy greater than 45 lumens per circuit-watt, and<br>II. all lamps automatically controlled so as to switch off when daylight is sufficient, and<br>III. light fittings controllable manually by occupants. | |

In the case of non-domestic buildings the requirements specify that the lighting system should meet minimum standards for:

a)
efficacy (averaged over the whole area of the applicable type of space in the building) and controls as set out in Table 1-4

OR

the LENI values as set out in Table 1-5;

b) The lighting should be metered to record its energy consumption in accordance with minimum requirements as set out in Table 1-6;

c) Lighting controls in new of existing buildings should follow the guidance in BRE Digest 498 Selecting Lighting Controls. Display lighting, where provided, should be controlled on dedicated circuits that can be switched off at times when people will not be inspecting exhibits or merchandise or being entertained.

*Table 1-4: Recommended minimum lighting efficacy with controls in new and existing non domestic buildings, UK Building regulations, Part L*

| **General lighting in office, industrial and storage spaces** | | **Initial luminaire lumens/circuit-watt**<br>60 |
|---|---|---|
| **Controls** | **Control factor** | **Reduced luminaire lumens/circuit-watt** |
| a. daylit space with photo-switching with or without override | 0.90 | 54 |
| b. daylit space with photo-switching and dimming with or without override | 0.85 | 51 |
| c. unoccupied space with auto on and off | 0.90 | 54 |
| d. unoccupied space with auto on and off | 0.85 | 51 |
| e. unoccupied space with auto on and off | 0.90 | 54 |
| a + c | 0.80 | 48 |
| a + d | 0.75 | 45 |
| b + c | 0.75 | 45 |
| b + d | 0.70 | 42 |
| e + c | 0.80 | 48 |
| e +d | 0.75 | 45 |
| General lighting in other types of space | | The average initial efficacy should be not less than 60 lamp lumens per circuit-watt |
| Display lighting | | The average initial-efficacy should be not less than 22 lamp lumens per circuit-watt |

*Table 1-5: Recommended maximum LENI (kWh/m2/year) in new and existing non domestic buildings, UK Building regulations, Part L*

| **Hours** | | | **Illuminance (lux)** | | | | | | | | **Display Lighting** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Total** | **Day** | **Night** | **50** | **100** | **150** | **200** | **300** | **500** | **750** | **1000** | **Normal** | **Shop window** |
| 1000 | 821 | 179 | 1.11 | 1.92 | 2.73 | 3.54 | 5.17 | 8.41 | 12.47 | 16.52 | 10.00 | |
| 1500 | 1277 | 223 | 1.66 | 2.87 | 4.07 | 5.28 | 7.70 | 12.53 | 18.57 | 24.62 | 15.00 | |
| 2000 | 1726 | 274 | 2.21 | 3.81 | 5.42 | 7.03 | 10.24 | 16.67 | 24.70 | 32.73 | 20.00 | |
| 2500 | 2164 | 336 | 2.76 | 4.76 | 6.77 | 8.78 | 12.79 | 20.82 | 30.86 | 40.89 | 25.00 | |
| 3000 | 2585 | 415 | 3.31 | 5.72 | 8.13 | 10.54 | 15.37 | 25.01 | 37.06 | 49.12 | 30.00 | |
| 3700 | 3133 | 567 | 4.09 | 7.08 | 10.06 | 13.04 | 19.01 | 30.95 | 45.87 | 60.78 | 37.00 | |
| 4400 | 3621 | 779 | 4.89 | 8.46 | 12.02 | 15.59 | 22.73 | 37.00 | 54.84 | 72.68 | 44.00 | 96.80 |
| 5400 | 4184 | 1216 | 6.05 | 10.47 | 14.90 | 19.33 | 28.18 | 45.89 | 68.03 | 90.17 | 54.00 | |
| 6400 | 4547 | 1853 | 7.24 | 12.57 | 17.89 | 23.22 | 33.87 | 55.16 | 81.79 | 108.41 | 64.00 | |
| 8760 | 4380 | 4380 | 10.26 | 17.89 | 25.53 | 33.16 | 48.43 | 78.96 | 117.12 | 155.29 | 87.60 | 192.72 |

*Table 1-6: Recommended minimum standards for metering of general and display lighting in new and existing non domestic buildings, UK Building regulations, Part L*

| | **Standard** |
|---|---|
| Metering for general or | a. kWh meters on dedicated lighting circuits in the electrical distribution, or |

| | |
|---|---|
| display lighting | b. local power meter coupled to or integrated in the lighting controllers of a lighting or building management system, or<br>c. a lighting management system that can calculate the consumed energy and make this information available to a building management system or in an exportable file format. (This could involve logging the hours run and the dimming level, and relating this to the installed load.) |

#### *1.5.1.7 Energy Efficiency Directive (EED)*

**Directive 2012/27/EU of the European Parliament and of the Council** amending **Directives 2009/125/EC** and **2010/30/EU**

Directive 2012/27/EU amends Directive 2009/125/EC on Ecodesign requirements for energy-related products and Directive 2010/30/EU on energy efficiency labelling of energy-related products, and repeals Directive 2004/8/EC on the promotion of cogeneration and Directive 2006/32/EC on energy end-use efficiency and energy services.

The Directive states, amongst other aspects, that Member States should establish long-term strategies to increase the energy efficiency renovation rate of the building stock and that public bodies' buildings should have an exemplary role. Also, the Directive states that by 30 April 2014, and every three years thereafter, Member States shall submit National Energy Efficiency Actions Plans (NEEAPs) that cover significant energy efficiency improvement measures and specify expected and/or achieved energy savings.

Member States had to transpose most of the Directive's provisions into national legislation by 5 June 2014.

The Directive establishes a common framework for promoting energy efficiency in the Union to ensure that the 20% energy efficiency target in 2020 (*i.e.* reaching a 2020 energy consumption of no more than 1483 Mtoe of primary energy consumption and no more than 1086 Mtoe of final energy consumption) is met and to paves the way for further energy efficiency afterwards.

The Directive provides for the establishment of indicative national energy efficiency targets for 2020 and requires the Commission to assess in 2014 whether the Union can achieve its target of 20% energy efficiency in 2020 and to submit its assessment to the European Parliament and the Council, accompanied, if necessary, by proposals for further measures.

The Energy Efficiency Directive lays down rules designed to remove barriers and overcome some of the market failures that impede efficiency in the supply and use of energy. For end-use sectors, the Directive focuses on measures that lay down requirements on the public sector, both as regards renovating the current building stock and applying high energy efficiency standards to the purchase of buildings, products and services. The Directive requires Member States to reach certain levels of final energy savings by using national energy efficiency obligation schemes or alternative policy measures. It requires regular mandatory energy audits for large companies and lays down a series of requirements regarding metering and billing.

For the energy supply sector, the Directive requires Member States to adopt a national heating and cooling assessment to develop the potential for high-efficiency generation and efficient district heating and cooling, and to ensure that spatial planning regulations are in line with these plans. Member States must adopt authorisation criteria that ensure that a cost-benefit analysis of the possibilities for cogeneration for all new and substantially refurbished electricity generation installations and industrial installations above a certain threshold is carried out and the results are taken into account. Member States should however be able to lay down conditions for exemption from this obligation where certain conditions are met. The Directive sets requirements on priority/guaranteed access to the grid, priority dispatch of electricity from high efficiency cogeneration and the connection of new industrial plants producing waste heat to district or cooling networks, and measures to encourage the use of demand side resources.

Other measures include requirements for national energy regulatory authorities to take due regard of energy efficiency, information and awareness-raising actions, requirements concerning the availability of certification schemes, actions to promote the development of energy services, and an obligation for Member States to remove obstacles to energy efficiency, including split incentives between the owner and tenant of a building or among building owners.

**Impacts of the Energy Efficiency Directive on lighting systems**
The Energy Efficiency Directive (EED) requires Member States to set up National Energy Efficiency Action Plans. An improved energy efficiency of lighting could be integrated in such NEEAPs.

#### *1.5.1.8 RoHS 2 – Directive on the Restrictions of Hazardous Substances in Electrical and Electronic Equipment*

**Directive 2011/65/EU of the European Parliament and of the Council**
**Directive 2002/95/EC of the European Parliament and of the Council** (recast)

The RoHS Directive restricts the use of Lead (Pb), Mercury (Hg), Cadmium (Cd), Hexavalent chromium (Cr6+), Polybrominated biphenyls (PBB) and Polybrominated diphenyl ether (PBDE) in manufacturing of certain electrical and electronic equipment sold in the European Union.

The new RoHS Directive, also known as RoHS 2, introduces new CE marking and declaration of conformity requirements. Before placing an EEE on the market, a manufacturer / importer / distributor must ensure that the appropriate conformity assessment procedure has been implemented in line with module A of Annex II to Decision No 768/2008/EC and affix the CE marking on the finished product. Since January 2013, electronic products bearing the CE Mark must meet the requirements of this new directive.

The new RoHS Directive scope has been extended to all electrical and electronic equipment (EEE), including medical devices, monitoring and control instruments, and EEE products not covered under the previous ten categories (the eleventh equipment category) unless specifically excluded.

**Impacts of RoHS 2 on lighting systems**
It is important for components of the system, such as lamps and controls, but not directly relevant for the system itself.

#### *1.5.1.9 Ecolabel Regulation*

**Regulation (EC) No 66/2010**

The EU Ecolabel helps consumers to identify products and services that have a reduced environmental impact throughout their life cycle, from the extraction of raw material through to production, use and disposal. Recognised throughout Europe, the EU Ecolabel is a voluntary label promoting environmental excellence which can be trusted.

**Impacts of Ecolabel on lighting systems**
Revised EU Ecolabel criteria for light sources were introduced in 2011[54]. For energy efficiency they require a minimum of 10% better than the 'A' class (as defined in the lamp energy label of Directive 98/11/EC) and require minimum lumen maintenance. They set minimum performance requirements for the number of switches, colour rendering and colour consistency. Environmental criteria relate to hazardous substances (e.g. mercury), substances regulated through REACH, marking of plastic parts and recycling of packaging.

#### 1.5.1.10 REACH

**Regulation (EC) No 1907/2006**

The REACH Regulation came into force on 1 June 2007 and deals with the Registration, Evaluation, Authorisation and Restriction of Chemical substances. It provides an improved and streamlined legislative framework for chemicals in the EU, with the aim of improving protection of human health and the environment and enhancing competitiveness of the chemicals industry in Europe. REACH places the responsibility for assessing and managing the risks posed by chemicals and providing safety information to users in industry instead of public authorities and promotes competition across the internal market and innovation.

Manufactures are required to register the details of the properties of their chemical substances in a central database, which is run by the European Chemicals Agency in Helsinki. The Regulation also requires the most dangerous chemicals to be progressively replaced as suitable alternatives are developed.

**Impacts of REACH on lighting systems**
Environmental criteria for Ecolabel relate to hazardous substances (e.g. mercury), substances regulated through REACH, marking of plastic parts and recycling of packaging.

#### 1.5.1.11 Green Public Procurement (GPP)

The EU Ecolabel and Green Public Procurement (GPP) initiatives are policy instruments designed to encourage the production and use of more environmentally friendly products and services through the certification and specification of products or services which have a reduced environmental footprint. They form part of the European Commission's action plan on Sustainable Consumption and Production and Sustainable Industrial Policy adopted on 16th July 2008.

Green public procurement (GPP) is defined as "*a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured*"[55].

[54] Commission Decision of 6 June 2011 on establishing the ecological criteria for the award of the EU Ecolabel for light sources, (2011/221/EU). OJ L148/13, 7.6.2011.
[55] COM (2008) 400 final. Public procurement for a better environment: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0400:FIN:EN:PDF

Public authorities are major consumers in Europe: they spend approximately €2 trillion annually, equivalent to some 19% of the EU's gross domestic product[56]. By using their purchasing power to choose goods and services with lower impacts on the environment, they can make an important contribution to sustainable consumption and production. Moreover, green purchasing also influences the market as in numerous cases public authorities have a large and dominant market share. By promoting and using GPP, public authorities can provide industry with real incentives for developing green technologies and products.

The Green Public Procurement's legislative document is the **Communication on ''Public procurement for a better environment'' COM (2008) 400 accompanied by the European GPP training toolkit.** The stated GPP target in the renewed Sustainable Development Strategy was that by the year 2010, the average level of GPP should have been the same as the 2006 level of the best performing Member States.

The approach under GPP is to propose two types of criteria for each sector covered:

- The **core criteria**, which are those suitable for use by any contracting authority across the Member States and address the key environmental impacts. They are designed to be used with minimum additional verification effort or cost increases.
- The **comprehensive criteria**, which are for those who wish to purchase the best environmental friendly products available on the market. These may require additional verification effort or a slight increase in cost compared to other products with the same functionality.

Just as the Ecolabel is a voluntary scheme, which means that producers, importers and retailers can choose to apply for the label for their products; GPP is also a voluntary instrument, which means that Member States and public authorities can determine the extent to which they implement it.

In June 2010, a **new procedure for EU GPP criteria development** was put in place in order to make the criteria development process more participatory and enhance synergies among different product-related policy instruments, for example EU GPP and EU Ecolabel[57]. The Procedure for the development and revision of EU GPP criteria is explained on the GPP website: http://ec.europa.eu/environment/gpp/gpp_criteria_procedure.htm

Both Ecolabelling and GPP criteria would be revised based on the outcomes of the Eco-lighting project[58], after been developed and agreed upon by experts, NGOs and stakeholders to create a credible and reliable way to make environmentally responsible choices. These criteria shall take into consideration the net balance between the environmental benefits and burdens; they shall be based on the most significant environmental impacts which are expressed as far as possible via technical key environmental performance indicators.

For several product groups common GPP criteria[59] are already developed in the framework of the training toolkit on GPP or are in the process of being developed (cfr work plan for 2015-2016)[60].
At present the following lighting equipment is covered:

[56] http://ec.europa.eu/environment/gpp/what_en.htm
[57] http://ec.europa.eu/environment/gpp/gpp_criteria_process.htm
[58] http://www.eco-lighting-project.eu/home
[59] http://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm
[60] http://ec.europa.eu/environment/gpp/gpp_criteria_wp.htm

- Indoor Lighting

Covering "*lamps, luminaires (light fittings) and lighting controls installed inside buildings*" with stated exceptions for specialist lighting.

- Street Lighting and Traffic Signals

Covering "*Fixed lighting installation intended to provide good visibility to users of outdoor public traffic areas during the hours of darkness to support traffic safety, traffic flow and public security*".

The relevant key environmental impacts identified in the GPP criteria for indoor lighting are:

- energy consumption
- polluting processes during manufacture
- hazardous constituents
- waste generation

**Impacts of GPP on lighting systems**

New EU Green Public Procurement (GPP) criteria for indoor lighting were introduced in 2012[61]. They relate not only to minimum luminous efficacy of the light sources (in lm/W), but also to lighting levels (W/m²/100 lux), lighting controls, etc
A revision of GPP criteria for street lighting is planned in 2016-2017.

#### *1.5.1.12 Construction products (CPD/CPR) Directive*

Some lighting system related products, e.g. windows, are building products and as such are covered by the Regulation 305/2011/EC (Construction Products Regulation - CPR), replacing Directive 89/106/EEC (Construction Products Directive - CPD). The regulation is embedded in the goal of creating a single market ("Article 95") for construction products through the use of CE Marking. It outlines basic requirements for construction works (as the sum of its components) that are the basis for the development of the standardization mandates and technical specifications i.e. harmonized product standards and European Assessment Documents (EADs).

While the CPR regulates the processes and the roles of the parties involved for all products alike, the necessary specific characteristics of each product are taken account of in the specific standard or EAD.

The basic idea is to harmonize the way the performance of a construction product is determined and declared in levels or classes while each member state may have individual requirements regarding the required minimum level or class for a given use.
The essential requirements for construction works are mechanical resistance and stability, safety in case of fire, hygiene, health and environment, safety and accessibility in use, protection against noise, energy economy and heat retention and sustainable use of natural resources.

The Regulation mandates standardisation organisations such as CEN to develop standards in consultation with industry (CEN TC 350 and CEN TC 351). A list of these standards can be found on the European Commission's website[62]. Where harmonised standards are not available, existing national standards apply.

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[61] http://ec.europa.eu/environment/gpp/pdf/criteria/indoor_lighting.pdf

[62] http://ec.europa.eu/enterprise/newapproach/standardization/harmstds/reflist/construc.html

In comparison to other products, the cross-border trade on construction products within the Internal Market has traditionally not been as commonplace. National markets often have obstacles preventing foreign products from being efficiently commercialized. Therefore, as one of the first efforts of such Community-wide harmonisation, the Council adopted in 1988 the Construction Products Directive (the CPD), based on Article 95, referring to the single market. The replacement of Council Directive 89/106/EEC by the Regulation (CPR) serves the aim to better define the objectives of Community legislation and make its implementation easier[63].

The CPR now includes in Annex I three basic requirements for construction works that specifically relate to ecological matters:

3) Hygiene, health and Environment
6) Energy Economy and heat retention
7) Sustainable use of natural resources

For the latter, it states in detail: "The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and ensure the following:

a) Recyclability of the construction works their materials and parts after demolition;
b) Durability of the construction works;
c) Use of environmentally compatible raw and secondary materials in the construction works."

Yet is must be kept in mind, that the CPR is – in spite of its name - a regulation which is focussed on the free trade of building products – as the European Commission has no competencies regarding building safety, which is within the competence of the member states.

As a result of this, the abovementioned Annex I "shall constitute the basis for the preparation of standardization mandates and harmonized technical specifications".

The particular nature of construction products, that are predominantly intended to be used by professionals (constructors, architects, civil engineers), has also brought along a need to differentiate the regulatory structure and the role of standards from the general horizontal rules of the Internal Market Package for Goods. Also the meaning of the CE marking in this context is specific: it attests that the information accompanying the product has been attained in accordance with the methods specified in the standards and that the manufacturer takes responsibility that the product has the declared performance.

The objective of the CPR is thus not to define the safety of construction products, but to ensure that reliable information is presented in relation to their performance. This is achieved by providing, mainly in standards, a common technical language, to be used not only by manufacturers, but also by public authorities when defining their requirements on construction works, directly or indirectly influencing the demands placed on the products to be used in them.

Finally it has to be noted, that according to CPR Article 3 it could in principle be possible, that the European Commission sets minimum performance requirements for construction products.

63 http://ec.europa.eu/enterprise/construction/index_en.htm

*"Where appropriate, the Commission shall also determine, by means of delegated acts in accordance with Article 60, the threshold levels for the performance in relation to the essential characteristics to be declared".* [64]

**Impacts of GPP on lighting systems**
So far, no direct impact on lighting systems is expected.

## 1.5.2 Member State legislation and other initiatives

### *1.5.2.1 Member state implementation of EPBD*

Member States have implemented the EPBD into their local legislation. For examples and a discussion see section 1.5.1.6.

### *1.5.2.2 Examples of Street lighting design regulation*

***Royal Decree 1890/2008 in Spain***

The energy efficiency regulations in street lighting installations, approved by Royal Decree 1890/2008, of 14th November, aims at improving the energy efficiency and saving, and therefore, decreasing greenhouse gas emissions; it provides the necessary feasibility conditions for both car drivers and pedestrians to have their security guaranteed as well as the one of the goods in the vicinity; it provides city life with a pleasant visual night time atmosphere; and curbs nightlight brightness or light pollution, reducing intrusive or unpleasant light.

***Guideline for Public Lighting 'ROVL 2011' in the Netherlands***

This guideline assists in selecting the road classes according to EN 13201-2 taking traffic density and possibilities for dimming into account.

***Italian standard UNI 11431 Applicazione in ambito stradale dei dispositive regolatori di flusso luminoso***

This standard assists in the application of dimming in public lighting.

***Italian decree of the 23th December 2013***

This decree on public lighting, including sports lighting, refers to the European regulations and gives guidance for design and tendering.

### *1.5.2.3 Examples of local luminaire labelling initiatives*

***Minergie luminaire label[65] in Switzerland***

Minergie is a luminaire label for the Suisse market, it takes into account luminaire efficiency (LER) and upper limits for an Energy Efficiency Index (EEI) in line with the formulas and requirements of the EU label Regulation (874/2012).

***'Milieukoopwijzer' in Belgium***

Milieukoopwijzer[66] is a database that contains luminaire labels and also takes into account luminaire efficiency. The highest level requires also a dimming interface.

[64] REGULATION (EU) No 305/2011, Article 3
[65] http://www.minergie.ch/leuchten.html
[66] http://www.milieukoopwijzer.be/criteria/armaturen

### 1.5.2.4 Sustainable building certification schemes that include lighting

#### BREEAM certification

Besides the EPBD, there exist also other methods to evaluate the sustainability of lighting. One of the most commonly applied is the BREEAM certification scheme. BRE, an independent British organization that originated from the former governmental laboratory 'Building Research Establishment', has developed this methodology for certification. BREEAM (Building Research Establishment's Environmental Assessment Method) is the leading and most applied method worldwide to measure the environmental performance of buildings, including lighting.

#### TEK Tool

In Germany an open freeware tool called 'TEK tool[67]' is available to analyse and decompose the energy use of non-domestic buildings. The building energy balance is decomposed into subsystems such as ventilation, heating, cooling, auxiliary energy and lighting. Lighting values are expressed in units of kWh/(y.m²) and target values for very high up to very low consumption are given (Figure 1-21) for various types of building applications, e.g. open plan office, cafeteria, class room, etc.

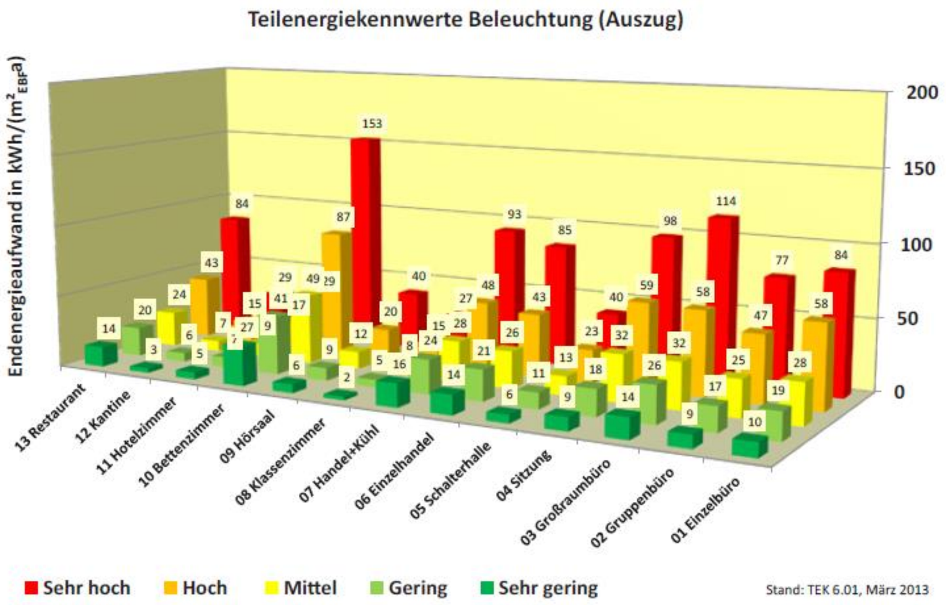


*Figure 1-21: Reference values in kWh/y.m² for lighting in various applications (source: IWU TEK Tool[68]).*

#### LEED (Leadership in Energy and Environmental Design)

LEED[69] is a sustainability certification for building projects. A building is assigned a sustainability score based on carefully established parameters. LEED was created in 2000 as an initiative of the US Green Building Council (USGBC). LEED factors in some

[67] http://www.enob.info/de/software-und-tools/projekt/details/tek-teilenergiekennwerte-fuer-nichtwohngebaeude-im-bestand/
[68] IWU (2014): 'Teilenergiekennwerte Neue Wege in der Energieanalyse von Nichtwohngebäuden im Bestand', ISBN: 978-3-941140-38-7
[69] http://www.usgbc.org/leed

50 parameters within nine categories. The process runs as follows: the client registers with the USGBC and this documentation leads to a provisional rating. After completion of the building, USGBC checks whether reality corresponds with the design. LEED certification does not come free of charge. LEED takes into account all aspects of a construction project including lighting.

### 1.5.3 Examples of similar legislation outside Europe

For USA, see section 1.4.3.

#### *1.5.3.1 Australia*

Australia specifies minimum lighting performance requirements in their buildings codes for new and existing as well as residential and non-residential buildings. Under these lighting power density limits are set as follows.

For non-residential buildings maximum illumination power density is prescribed by space type (Table J6.2a) with adjustments for control devices (Table J6.2b)

For residential buildings multi-occupancy (class 2): Maximum illumination power density is prescribed by space type (Table J6.2a) with adjustments for control devices (Table J6.2b), in subsequent Table 1-7.

*Table 1-7: List of tables extracted from Australian Building codes*

**Table J6.2a MAXIMUM ILLUMINATION POWER DENSITY**

| Space | Maximum illumination power density (W/ $m^2$) |
|---|---|
| Auditorium, church and public hall | 10 |
| Board room and conference room | 10 |
| Carpark - general | 6 |
| Carpark - entry zone (first 20 m of travel) | 25 |
| Common rooms, spaces and corridors in a Class 2 building | 8 |
| Control room, switch room, and the like | 9 |
| Corridors | 8 |
| Courtroom | 12 |
| Dormitory of a Class 3 building used for sleeping only | 6 |
| Dormitory of a Class 3 building used for sleeping and study | 9 |
| Entry lobby from outside the building | 15 |
| Health-care - children's ward | 10 |
| Health-care - examination room | 10 |
| Health-care - patient ward | 7 |
| Health-care - all patient care areas including corridors where cyanosis lamps are used | 13 |
| Kitchen and food preparation area | 8 |
| Laboratory - artificially lit to an ambient level of 400 lx or more | 12 |
| Library - stack and shelving area | 12 |
| Library - reading room and general areas | 10 |

Table J6.2a MAXIMUM ILLUMINATION POWER DENSITY (Continued)

| Space | Maximum *illumination power density* (W/m²) |
|---|---|
| Lounge area for communal use in a Class 3 building or Class 9c *aged care building* | 10 |
| Museum and gallery - circulation, cleaning and service lighting | 8 |
| Office - artificially lit to an ambient level of 200 lx or more | 9 |
| Office - artificially lit to an ambient level of less than 200 lx | 7 |
| Plant room | 5 |
| Restaurant, café, bar, hotel lounge and a space for the serving and consumption of food or drinks | 18 |
| Retail space including a museum and gallery whose purpose is the sale of objects | 22 |
| *School* - general purpose learning areas and tutorial rooms | 8 |
| *Sole-occupancy unit* of a Class 3 building | 5 |
| *Sole-occupancy unit* of a Class 9c *aged care building* | 7 |
| Storage with shelving no higher than 75% of the height of the aisle lighting | 8 |
| Storage with shelving higher than 75% of the height of the aisle lighting | 10 |
| Service area, cleaner's room and the like | 5 |
| Toilet, locker room, staff room, rest room and the like | 6 |
| Wholesale storage and display area | 10 |

**Notes:**

1. In areas not listed above, the maximum *illumination power density* is—
   - (a) for an illuminance of not more than 80 lx, 7.5 W/m$^2$; and
   - (b) for an illuminance of more than 80 lx and not more than 160 lx, 9 W/m$^2$; and
   - (c) for an illuminance of more than 160 lx and not more than 240 lx, 10 W/m$^2$; and
   - (d) for an illuminance of more than 240 lx and not more than 320 lx, 11 W/m$^2$; and
   - (e) for an illuminance of more than 320 lx and not more than 400 lx, 12 W/m$^2$; and
   - (f) for an illuminance of more than 400 lx and not more than 480 lx, 13 W/m$^2$; and
   - (g) for an illuminance of more than 480 lx and not more than 540 lx, 14 W/m$^2$; and
   - (h) for an illuminance of more than 540 lx and not more than 620 lx, 15 W/m$^2$.
2. For illuminance levels greater than 620 lx, the average *light source efficacy* must not be less than 80 Lumens/W.

Table J6.2a MAXIMUM ILLUMINATION POWER DENSITY (Continued)

| Space | Maximum *illumination power density* (W/m²) |
|---|---|

3. For enclosed spaces with a Room Aspect Ratio of less than 1.5, the maximum *illumination power density* may be increased by dividing it by an adjustment factor for room aspect which is:

   0.5 + (Room Aspect Ratio/3)

   The Room Aspect Ratio of the enclosed space is determined by the formula:

   A/(H × C)

   Where:

   A is the area of the enclosed space

   H is the height of the space measured from the floor to the highest part of the ceiling

   C is the perimeter of the enclosed space at floor level
4. In addition to 3, the maximum *illumination power density* may be increased by dividing it by the *illumination power density* adjustment factor in **Table J6.2b** where applicable and where the control device is not installed to comply with **J6.3**.
5. Circulation spaces are included in the allowances listed in the Table.

**Table J6.2b ILLUMINATION POWER DENSITY ADJUSTMENT FACTOR FOR A CONTROL DEVICE**

| Item | Description | *Illumination power density* adjustment factor |
|---|---|---|
| Lighting timer in accordance with **Specification J6** | For corridor lighting | 0.7 |
| Motion detector in accordance with **Specification J6** | (a) Where— (i) at least 75% of the area of a space is controlled by one or more motion detectors; or (iii) an area of less than 200 $m^2$ is switched as a block by one or more detectors. | 0.9 |
| | (b) Where up to 6 lights are switched as a block by one or more detectors | 0.7 |
| | (c) Where up to 2 lights are switched as a block by one or more detectors. | 0.55 |

**Table J6.2b ILLUMINATION POWER DENSITY ADJUSTMENT FACTOR FOR A CONTROL DEVICE (Continued)**

| Item | Description | *Illumination power density* adjustment factor |
|---|---|---|
| Manual dimming system Note 1 | (a) Where at least 75% of the area of a space, in other than a *sole-occupancy unit* of a Class 2 building or a Class 4 part, is controlled by manually operated dimmers. | 0.95 |
| | (b) Where at least 75% of the area of a space, in a *sole-occupancy unit* of a Class 2 building or a Class 4 part, is controlled by manually operated dimmers. | 0.85 |
| Programmable dimming system Note 2 | Where at least 75% of the area of a space is controlled by programmable dimmers. | 0.85 |
| Dynamic dimming system Note 3 | Automatic compensation for lumen depreciation. | The design lumen depreciation factor of not less than— (i) for fluorescent lights, 0.9; or (ii) for high pressure discharge lights, 0.8. |
| Fixed dimming Note 4 | Where at least 75% of the area is controlled by fixed dimmers that reduce the overall lighting level and the power consumption of the lighting. | % of full power to which the dimmer is set divided by 0.95. |
| Daylight sensor and dynamic lighting control device in accordance with **Specification J6** – dimmed or stepped switching of lights adjacent *windows* | (a) Lights within the space adjacent to *windows* other than *roof lights* for a distance from the *window* equal to the depth of the floor to window head height. | 0.5 Note 5 |
| | (b) Lights within the space adjacent to *roof lights*. | 0.6 Note 5 |

Notes:

1. Manual dimming is where lights are controlled by a knob, slider or other mechanism or where there are pre-selected scenes that are manually selected

Table J6.2b ILLUMINATION POWER DENSITY ADJUSTMENT FACTOR FOR A CONTROL DEVICE (Continued)

| Item | Description | *Illumination power density* adjustment factor |
|---|---|---|

2. Programmed dimming is where pre-selected scenes or levels are automatically selected by the time of day, photoelectric cell or occupancy sensor.
3. Dynamic dimming is where the lighting level is varied automatically by a photoelectric cell to either proportionally compensate for the availability of daylight or the lumen depreciation of the lamps.
4. Fixed dimming is where lights are controlled to a level and that level cannot be adjusted by the user.
5. The *illumination power density* adjustment factor is only applied to lights controlled by that item. This adjustment factor does not apply to tungsten halogen or other incandescent sources.
6. A maximum of two other *illumination power density* adjustment factors for a control device can be applied to an area. Where more than one *illumination power density* adjustment factor (other than for room aspect) apply to an area, they are to be combined using the following formula:

   A x ( B + [ ( 1 - B ) / 2 ] )

   Where

   A is the lowest applicable *illumination power density* adjustment factor; and

   B is the second lowest applicable *illumination power density* adjustment factor.

### 1.5.3.2 Canada

Canada has a model National Energy Code for Buildings (NECB) that has some similarities with the ASHRAE 90.1 model building code used in the USA. The most recent version of the NECB was issued in 2011.

The lighting requirements do not apply to lighting within dwelling units.

*Options for Compliance*
Aside from alternative solutions that may always be proposed for compliance with nati onal model codes, the NECB provides three approaches to compliance:

- Prescriptive Path – "simple" prescriptive requirements
- Trade-Offs – allowed between related building elements (e.g., higher roof insulation levels may be traded off against lower wall insulation levels)
- Performance Compliance Paths – full-building energy-use modeling

NECB Part 4 – Lighting

*Lighting Power Limits*
Limits are specified in terms of maximum lighting power. Lower levels are more stringent.

Interior and Exterior Lighting Power [Subsections 4.2.1. and 4.2.3.]
For interior lighting, not within dwelling units, two approaches are provided:

- building area method [Article 4.2.1.5.]
- the space-by-space method [Article 4.2.1.6.].

If 10% or more of the gross lighted area of the building can be classified as a different building type (e.g. parking garage), the space-by-space method must be used. The gross lighted area would not include the area within dwelling units.
For the space-by-space method, the power allowances in individual spaces may be exceeded provided the total installed power does not exceed the total allowed for all of the spaces.

A base allowance is specified for exterior lighting.

*Lighting Controls [Subsections 4.2.2. and 4.2.4.]*
Automatic time-of-day, occupant sensors or occupant signals must be installed for most interior spaces other than dwelling units. Numbers, characteristics and locations are specified. Additional controls are required where spaces have significant day-lighted area.

Automatic time-of-day, occupant sensors or occupant signals must be installed for most interior spaces other than dwelling units. Numbers, characteristics and locations are specified. Additional controls are required where spaces have significant day-lighted area.

Automatic time-of-day, photo-sensors or similar controls are required for exterior lighting.

*Lighting Trade-Offs [Sections 4.3.]*
In addition to consideration of lighting energy allowances, the calculations account for annual day and night operating times, daylight harvesting, occupancy and personal controls.

*Comparison with ASHRAE 90.1 2010.*
While there are many similarities between the NECB 2011 and ASHRAE 90.1 2010 there are also differences in the way each code/standard describes building types or technologies. The baselines for different parts and technologies of the code/standard will sometimes differ throughout the documents themselves. This comparison addresses only the Prescriptive Paths in each document.

The following are the major differences in approach between the NECB 2011 and ASHRAE 90.1 as they apply to lighting systems:

- The NECB applies to new construction and additions, ASHRAE requirements also apply to alterations to existing buildings.
- The NECB has a trade-off route within lighting, HVAC and service water heating (e.g. day lighting controls), ASHRAE does not.

#### 1.5.3.3 China

In China the legally enforceable, mandatory standard for visual comfort (300 lux) and power density (11 watts/$m^2$) are defined in GB5034-2004, *Standard for lighting design of buildings*.

#### 1.5.3.4 India

The Energy Conservation Building Code of 2007 developed by the Ministry of Power includes specifications for both indoor and outdoor lighting energy performance. The code applies to commercial buildings and is voluntary.

#### 1.5.3.5 Switzerland

The Swiss MINERGIE building code is a model code for all the Swiss Cantons. The lighting requirements are specified in Norm SIA 380/4:2009 and apply to new construction and renovation of existing buildings for non-residential buildings. Table 1-8 specifies the maximum permitted LENI (EN 15193) and LPD values for each space type where tli is the assumed hours of lighting operation per annum in the LENI calculation (EN 15193).

*Table 1-8: Maximum permitted LENI and LPD values for different space types in Swiss building codes, Norme SIA 380/4:2009*

| | Minimum requirements | | |
|---|---|---|---|
| | LENI | LPD | tli |
| Space | (kWh/m$^2$) | (W/m$^2$) | [h] |
| Hotel room | 4 | 3 | 1270 |
| Reception | 17 | 4.5 | 3800 |
| Individual office | 24 | 16 | 1500 |
| Open office | 29 | 12.5 | 2320 |
| Meeting room | 13 | 16 | 820 |
| Hall counters, customer area | 12 | 8.5 | 1450 |
| Classroom | 21 | 14 | 1530 |
| Teachers room | 17 | 11.5 | 1410 |
| Library | 11 | 7 | 1610 |
| Auditorium | 26 | 12.5 | 2110 |
| Special rooms | 21 | 14 | 1530 |
| Furniture shop | 51 | 15.5 | 3270 |
| Food shop | 73 | 21.5 | 3400 |
| DIY centre | 73 | 21.5 | 3400 |
| Supermarket | 96 | 27.5 | 3480 |
| Hyper market | 118 | 33.5 | 3530 |
| Jewellers | 139 | 43 | 3240 |
| Restaurant | 17 | 7 | 2410 |
| Self-service restaurant | 11 | 6 | 1800 |
| Restaurant kitchen | 38 | 16 | 2400 |
| Self-service restaurant kitchen | 29 | 12.5 | 2280 |
| Auditorium | 34 | 11 | 3130 |
| Sports hall | 34 | 11 | 3140 |
| Exhibition centre | 42 | 11 | 3900 |
| Hospital room | 17 | 4.5 | 3800 |
| Hospital service office | 54 | 14 | 3800 |
| Medical facilities | 24 | 16 | 1500 |
| Production (heavy work) | 31 | 11 | 2880 |
| Production ( detailed work) | 48 | 15 | 3250 |
| Warehouse | 40 | 11.5 | 3520 |
| Gymnasium | 31 | 10.5 | 2970 |
| Fitness centre | 34 | 10 | 3440 |
| Covered swimming pool | 28 | 11.5 | 2480 |
| Loading bays | 11 | 7 | 1500 |
| Toilet/shower block | 28 | 11 | 2500 |
| WC | 31 | 17.5 | 1770 |
| Cloakrooms and showers | 34 | 10 | 3430 |
| Parking lot | 6 | 3 | 2130 |
| Laundromat | 46 | 13 | 3500 |
| Cold storage room | 0.5 | 5 | 0 |

## 1.6 Quick Scan

**Objective:**

**Important note: The findings presented in the discussion below are indicative and made only for the purpose on an initial screening exercise. They will thus be updated in the course of conducting the later Tasks. Therefore this section is mainly printed in grey and will not be updated in revisions of this Task 0.**

According to the MEErP: "Task 0 is an optional task for the case of large or inhomogeneous product groups, where it is recommended to carry out a first product screening, considering the environmental impact and potential for improvement of the products as referred to in Article 15 of the Ecodesign Directive. The objective is to re-group or narrow the product scope, as appropriate from an ecodesign point of view, for the subsequent analysis in Tasks 1-7."

This preparatory study on lighting systems follows from the request for services ENER/C3/2012-418 LOT1/05. The Quickscan is an initial screening, based on available information from previous studies and other sources. The objective is to re-group or narrow the product scope, as appropriate from an Ecodesign point of view, for the subsequent analysis. This is done by gathering initial data for the study tasks in order to allow scrutiny against the Article 15 criteria of the Ecodesign Directive 2009/125/EC. Accordingly, the structure of the Quickscan is based on the three major criteria in Article 15, paragraph 2, as explained in section 3.1.1.

According to paragraph 2 of Article 15 of Ecodesign Directive 2009/125/EC energy-related products such as lighting systems have to:

1. represent a significant volume of sales and trade, indicatively more than 200 000 units a year within the Community to the most recently available figures;
2. have a significant environmental impact within the Community – as specified in the Community strategic priorities as set out in Decision No 1600/2002/EC – considering the quantities placed on the market and/or put into service;
3. present significant potential for improvement in terms of its environmental impact without entailing excessive costs, taking into account in particular:
   i. the absence of other relevant Community legislation or failure of the market forces to address the issue properly; and
   ii. a wide disparity in the environmental performance of products available on the market with equivalent functionality.

These three criteria will be addressed in the Quickscan as guiding principles to determine the potential of possible Ecodesign, energy labelling, and/or energy performance of buildings requirements.

Additionally, the provisions of the Ecodesign Directive 2009/125/EC require consideration of the (entire) life cycle of the product and all its significant environmental aspects (including energy efficiency during the use phase of the product) (article 15, paragraph 4, item (a)). Furthermore, implementing measures shall meet the following criteria (article 15, paragraph 5):

a) there shall be no significant negative impact on the functionality of the product, from the perspective of the user;
b) health, safety and the environment shall not be adversely affected;

c) there shall be no significant negative impact on consumers in particular as regards the affordability and the life cycle cost of the product;
d) there shall be no significant negative impact on industry's competitiveness;
e) in principle, the setting of an Ecodesign requirement shall not have the consequence of imposing proprietary technology on manufacturers; and,
f) no excessive administrative burden shall be imposed on manufacturers.

This chapter gives an overview of the Quickscan to provide an insight into the economic and environmental importance of lighting systems and to define potential environmental improvement actions. The results from the Quickscan will identify the most relevant issues for determining whether lighting systems should be included under the "priority list" of products covered by the Second Working Plan on Ecodesign.

**So far 'Lighting systems' are not exactly defined as 'traded products' for which a commonly agreed 'unit sold' and product code is available in official product sales statistics such as PRODCOM. Therefore checking significance compared to 200 000 units sold is more complex than for some product groups. Nonetheless it seems clear that considerably more than 200000 lighting systems are installed each year across the EU.**

**In addition, the potential for energy savings are comfortably above 2 TWh per year and hence can be considered to be significant within the terms applied for the Ecodesign Directive.**

### 1.6.1 Data sources used

The data sources used are:

- Commission Staff Working Document (3009/324): 'Accompanying document to the Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council' full impact assessment.
- Commission Staff Working Document (3009/327): 'Commission Staff Working Document (3009/324): 'Accompanying document to the Commission Regulation implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council' full impact assessment.
- Commission Staff Working Document: Annex 1 working document on possible measures targeting the energy efficiency of lighting in the tertiary sector Presented by the Directorate General for Energy for consultation of the Consultation Forum running from 6 July to 15 September 2010.
- Lighting preparatory studies on lot 8, lot 9, lot 19 (www.eup4light.net).
- Road network statistics from Eurostat (length of roads).
- Building stock statistics from Buildings Performance Institute Europe (BPIE) (surface areas per sector).

- Waide et al., 'The scope for energy and CO2 savings in the EU through the use of building automation technology', Final report August 2013. (Note, this processed BPIE building stock data).
- Typical lighting operational hours and power density (W/m²) per sector/building type according to standard EN 15193.
- Outdoor lighting estimate for non-public lighting as found in literature[70].
- Building construction and renovation statistics from literature[71].
- VHK (2011), Study on Amended Working Plan under the Ecodesign Directive: Final Report, commissioned by the European Commission, version 16 December 2011. This study identifies traffic lights and lighting controls.
- VHK (2013), Omnibus Review Study on Cold Appliances, Washing Machines, Dishwashers, Washer-Driers, Lighting, Set-top Boxes and Pumps, draft interim report (available through www.eup-network.de).

### 1.6.2 Lighting Installation stock data rough estimate

**Important note: These are indicative for a first screening only and will be updated in later Tasks. Therefore this section is mainly printed grey and will not be updated in revisions of this Task 0.**

In the literature there is data available concerning the size of the existing building stock72 which can be combined with indicative operational hours of lighting and power density in typical sectors; this results in an estimate to allocate the EU27 power consumption per sector (Table 1-9).

*Table 1-9: Relative indoor lighting power consumption per sector*

| sector | EU 27 area (million m²) | Share of total area % | time (h/y) | W/m² | % TWh |
|---|---|---|---|---|---|
| Education | 1001 | 17% | 2000 | 20 | 10% |
| Hotels & restaurants | 648 | 11% | 3750 | 22,5 | 13% |
| Hospitals | 412 | 7% | 5000 | 23 | 11% |
| Retail | 883 | 15% | 5000 | 25 | 27% |
| Offices | 1354 | 23% | 2500 | 20 | 16% |
| Other | 1590 | 27% | 2980 | 20 | 23% |
| other (% sports) | not available | assumption 1/3 | 4000 | 20 | 10% |
| other (% industry) | not available | assumption 1/3 | 4000 | 20 | 10% |
| other (% any other) | not available | assumption 1/3 | 1000 | 20 | 3% |
| households | 17810 | not applicable | 630 | NA | NA |
| | source: Waide et al. Data (8/2013) | | source: EN 15193 | | estimate |

[70] http://www.milieurapport.be/Upload/main/AG2007_2%207c_9%20met%20voorblad.pdf

[71] Ecofys (2011): 'Panorama of the European non-residential construction sector'-Final report

[72] Waide et al., 'The scope for energy and CO2 savings in the EU through the use of building automation technology', Final report August 2013

Lot 9 contained an estimate of the energy consumption of street lighting in the EU. Little data is available on other outdoor applications, however, an estimate of the share of outdoor lighting energy use by application derived according to the literature73 can be found in Table 1-10.

*Table 1-10: Estimated share in outdoor lighting power consumption per sector*

| sector | % |
|---|---|
| public lighting | 55,6 |
| industry sector outdoor | 8,6 |
| service & recreational sector | 23,4 |
| households | 2,9 |
| agriculture green houses | 9,5 |

### 1.6.3 Reference Total energy consumption of the lighting stock in 2007 (rough estimate) (TWh)

Savings are relative to the energy consumption of the lighting stock, therefore this section contains a rough estimate of the lighting stock in 2020, see Table 1-11.
The upper part of Table 1-11 subdivides the data according to the regulation from which they have been derived, i.e. 245/2009 (Tertiary), 244/2009 (NDLS) and 1194/2012 (DLS).

The lower part of the table attempts an alternative subdivision, of the same total values, into an outdoor share, an indoor-residential share and an indoor-non-residential share.

Notes about this 2020 estimate:

- This energy estimate is limited to the scope of existing EU policy measures and therefore does not include, for example, special purpose lamps (estimated to consume 58 TWh in 2007) and/or some types of controls.
- The 2020-data in the table have been derived from Impact Assessment reports that in their turn depended heavily on the data collected and derived for the Preparatory Studies during the years 2005-2007. The clear impression is that the progress, development and market-introduction of LED lamps is much faster than was assumed in those years and also therefore that this estimate is inaccurate.
- This estimate neglects interactive effects with the building energy balance as illustrated in Figure 1-1, for example energy savings in lighting could also reduce the building cooling energy demand.

In the context of this quick scan it is not feasible to develop a new and more refined models for the lighting stock, for the corresponding total energy consumption, and for the energy savings related to the Eco-design and –labelling measures which have already been implemented.

[73] Van Tichelen, Bossuyt, Mira-2007 'Achtergronddocument Thema hinder: lichthinder', www.milieurapport.be

*Table 1-11: Rough estimate of Electrical Energy Consumption of the EU27 lighting stock based on the data of the Impact Assessment reports associated with the Regulations regarding the Ecodesign measures.*

| Source | Main Lamp Types | TWh base year[74] | TWh BAU[75] 2020 | TWh ECO[76] 2020 | TWh ECO 2020 – base year | TWh Savings ECO 2020 – BAU 2020 |
|---|---|---|---|---|---|---|
| 245/2009[77] (Tertiary) | LFL, CFLni, HID | 200 | 260 | 222 | +22 | -38 |
| 244/2009[78] (NDLS) | GLS, CFLi, HL, (LED) | 112 | 135 | 84 | -28 | -51 |
| 1194/2012[79] (DLS) | GLS-R, HL-R, (LED) | 30 | 50 | 26 | -4 | -24 |
| **Total** | **All above** | **342** | **445** | **332** | **-10** | **-113** |
| | | | | | | |
| *Estimated Outdoor/Indoor Subdivision compatible with above totals* | | | | | | |
| Outdoor | HID | 65 | 84 | 72 | +7 | -12 |
| Indoor Residential | GLS, CFLi, HL, (LED) | 109 | 131 | 82 | -27 | -49 |
| Indoor Non-Residential | LFL, CFLni (LED) | 168 | 230 | 178 | +10 | -52 |
| **Total** | **All above** | **342** | **445** | **332** | **-10** | **-113** |

### 1.6.4 Link between reference energy consumption and installation stock

At the moment we can only provide an educated guess based on perception; to our knowledge lamp manufacturers have no accurate data concerning where lamps are used or don't want to disclose it for commercial reasons. The assumption on the relation between sector and lamp technology is summarised in the next table:

[74] Differs from source to source, year 2005 or 2007
[75] Business As Usual, based on state and trends of 2005 or 2007
[76] ECO includes the effect of measures as specified in the source
[77] Impact Assessment 2009-0324, for Regulation 245/2009, sub-option 2 of Annex II
[78] Impact Assessment 2009-0327, for Regulation 244/2009, does not contain full energy data for BAU and ECO scenarios. Data have been taken from Preparatory study Lot 19; figure 8-6 for BAU; figure 8-36 2b for ECO.
[79] Impact Assessment 2012-0419, for Regulation 1194/2012; para 2.5.4 for BAU; para 5.2.1 for Lbl Min II (stage 3 at EEI=0.95 applied) for ECO

*Table 1-12: Estimated share of lamp technology per sector indoor*

| | LFL&HID | NDLS | DLS |
|---|---|---|---|
| sector | % | % | % |
| Education | 100% | 0% | 0% |
| Hotels & restaurants | 34% | 33% | 33% |
| Hospitals | 90% | 5% | 5% |
| Retail | 40% | 20% | 40% |
| Offices | 100% | | |
| Other | | | |
| other (% sports) | 90% | 5% | 5% |
| other (% industry) | 90% | 5% | 5% |
| other (% any other) | 90% | 5% | 5% |

Combining these assumptions with the rough estimate of the lighting stock energy consumption in 2020 results in the following estimate per indoor sector (Table 1-13):

*Table 1-13: Estimated annual power consumption of indoor lighting stock per sector (2007)*

| sector | TWh |
|---|---|
| Education | 17,2 |
| Hotels & restaurants | 23,5 |
| Hospitals | 20,3 |
| Retail | 47,3 |
| Offices | 29,0 |
| Other | |
| other (% sports) | 18,0 |
| other (% industry) | 18,0 |
| other (% any other) | 4,6 |
| households | 82,0 |

For outdoor lighting the data on energy consumption per sector from Table 1-11 and Table 1-13 can be combined to derive the values in (Table 1-14).

*Table 1-14: Estimated annual power consumption of outdoor lighting stock per sector (2007)*

| sector | TWh |
|---|---|
| public lighting | 40,1 |
| industry sector outdoor | 6,2 |
| service & recreational sector | 16,9 |
| households | 2,1 |
| agriculture green houses | 6,8 |
| Total outdoor | 72,0 |

## 1.6.5 Lighting system related improvement options

### *1.6.5.1 Introduction to lighting system improvement options*

The focus of the improvement options discussed in this section is on improving energy efficiency. This means that other environmental impacts are neglected in the quick scan, e.g. in street lighting replacing asphalt by concrete to increase the road surface reflection might also impact VOC emission. Also the potential positive impact on outdoor light pollution will not be repeated hereafter (see Lot 9). The main reasons for this decision are the added complexity and/or lack of available data. It is suggested to look at those impacts in a full preparatory study for selected and relevant improvement options only. Improvement options related to increases in lamp efficacy, e.g. to A+, will not be discussed hereafter. They are discussed in the OMNIBUS review.

*The focus is therefore on system level improvement options that are only related to energy efficiency* and that were not dealt with in existing legislation.

The parameters and the related system components that are used in the quick scan are explained in Task 1.

In the following sections five levels of system related improvement options are discerned:

1. *Redesign the building*/room or street;
2. *Change the luminaire and lighting control system* and maintain the other surrounding infrastructure (poles, light point locations, …);
3. *Change the luminaire but not the lighting control system;*
4. *Retrofit lamp, ballast and optic*
5. *Retrofit lamp and ballast*

The highest level, e.g. 1 'Redesign the building', can always be combined with a lower level, e.g. 'Change the luminaire'.

### *1.6.5.2 Redesign the building/room or street improvement option*

In this case the redesign includes:

- lighting and building energy balance calculation with optimisation;
- choosing windows for daylight entrance;
- building the lighting infrastructure i.e. cables, suspension or poles;
- choosing and placing luminaires;
- choosing and placing lamps or light sources;
- choosing and placing ballasts or drivers;
- installing the lighting control system;
- choosing appropriate surface reflection requirements;

- iterative redesign steps to have a close fit to lighting requirements for tertiary lighting as defined in standards EN 12464-1&2 and EN 13201-2, e.g. fit to maximum +5 % above the requirement of 500 lx.

Luminaires, lamps and ballasts were selected to be the best available products on the market and moreover ballasts or drivers are dimmable, electronic ones. The dim ability, coupled to a lighting control system, allows energy savings accordingly to the traffic density (street lighting) or daylight (offices and indoor lighting).

#### 1.6.5.3 Change the luminaire and the external lighting control system improvement option

This option saves the basic infrastructure and only replaces:

- luminaires;
- lamps or light sources;
- ballasts or drivers;
- lighting control system.

Luminaires, lamps and ballasts were selected to be the best available products on the market.
Ballasts or drivers shall be dimmable and electronic ones and play an important role in this option. Dimming also enables close matching of the illumination to the lighting requirements for non-domestic lighting as defined in standards EN 12464-1&2 and EN 13201-2 and therefore provides energy saving. Otherwise, there is an initial over-illumination in projects where the maintenance factor is taken into account; a constant illumination control system such as defined in EN 15193 can therefore provide additional savings.

#### 1.6.5.4 Change the luminaire but not an external lighting control system improvement option

In existing installations of the previous option where no lighting control system can be installed, it is possible to just replace luminaires.
In this case dimming can also be useful e.g. when dimming can be done to fine tune matching with the minimum illumination requirements taking into account real local conditions such as reflections and the available lamp wattages. It is also possible to have an integrated light or presence sensor to control the light output.

#### 1.6.5.5 Retrofit lamp, ballast and optic improvement option

If the luminaires in an installation are equipped with poor optics, only lamps, ballasts and optics can be replaced. In this option the lamp is replaced by a directional light source that partially bypasses the luminaire optics. This is useful in existing luminaires with poor optical efficiency. Replacing a fluorescent lamp by a retrofit LED lamp can be an example of this solution.

#### 1.6.5.6 Retrofit lamp and ballast improvement option

See the Omnibus study.

#### 1.6.5.7 More frequent operation and maintenance of the lighting system according to the design

This can reduce calculated maintenance factors and therefore initial and total energy in use for the life of the lighting system.
Also in existing designs it can provide savings when constant illumination control systems are implemented, see 1.6.5.3.

#### 1.6.5.8 Reference Worst Case (WC) 2020 compared to BAT 2020 for street lighting (outdoor)

The calculation shown in table 1-15 below is made for a street in a slow traffic area in line with the Lot 9 Preparatory Study for Public Street Lighting.

The base case already takes into account the Ecodesign requirements for 2017 as published in Commission Regulation 245:

- the lamp type is an HPS with enhanced xenon-pressure and non-dimming magnetic ballast;
- the luminaire is a luminaire without optics and with ingress protection IP45 as the regulation does not impose any requirement for luminaires; and,
- low performing optics and installation (UF).

The BAT 2017 uses:

- an improved MH-lamp of the new generation;
- improved UF;
- a dimmable, electronic ballast with appropriate control system;
- a luminaire with BAT optic, IP65 and self-cleaning glass and thus high LMF.

The BAT 2020 LED has:

- LED light source with assumed efficiency of 120 lm/W as forecast by Lighting Europe;
- a dimmable electronic driver with appropriate control system;
- improved UF, it assumes that LED enables better control of the light distribution;
- a luminaire with high LMF.

*Table 1-15: Worst Case with existing legislation compared to BAT 2020 at system level for street lighting*

| | HPS-70W | MH-60W | LED |
|---|---|---|---|
| | Worst Case 2017, Slow Traffic | MH BAT 2020 2017, Slow Traffic | LED BAT 2020 2017, Slow Traffic |
| ballast type | elecronic | electronic, dim | electronic, dim |
| IP(ingress) | 45 | 65 | 65 |
| ηgear | 0,90 | 0,90 | 0,90 |
| BGF | 1 | 1,6 | 1,6 |
| ηlamp(lm/w) | 94 | 120 | 120 |
| LLMF | 0,95 | 0,95 | 0,80 |
| LOR | 0,5 | 0,75 | 1,00 |
| LMF | 0,84 | 0,90 | 1,00 |
| U | 0,22 | 0,67 | 0,80 |
| LPDi(W/100 lm) | 13,43 | 1,35 | 0,90 |

**Conclusion:**

This street lighting example, illustrates that the energy consumption per year and per useful lumen when comparing the Worst Case projected for 2017 with the BAT can drop from 13.43 W per 100 functional lumens to 0.9 W per 100 functional lumens, i.e. **an energy saving of over 93%.**

### *1.6.5.9 Reference Worst Case (WC) 2020 compared to BAT 2020 for office lighting (indoor)*

The calculated example in the table below is made for a cellular office with luminaires with direct light output, in line with the lot 8 Preparatory Study for Office Lighting.

The base case assumes a T8-LFL, a non-dimmable electronic ballast with a directional light source luminaire (CIE flux code N2>0.8) and relatively poor optics (LOR) in line with the 2017 legislation.

The BAT case uses the improved T5-LFL and a dimmable, electronic ballast with lighting control i.e. presence detection and daylight responsive dimming (BGF).

The LED solution assumes an efficiency of 120 lm/W and also a dimmable, electronic driver with lighting control i.e. presence detection and daylight responsive dimming.

*Table 1-16: Worst Case with existing legislation compared to BAT 2020 at system level for office lighting*

| | BC2020 | BATLED | BAT_T5 |
|---|---|---|---|
| Room length (window) | 3,6 | 3,6 | 3,6 |
| Room depth | 5,4 | 5,4 | 5,4 |
| distance lum-work plane | 2 | 2 | 2 |
| SHR | 1 | 1 | 1 |
| Reflectance ceiling | 0,7 | 0,7 | 0,7 |
| Reflectance Walls | 0,5 | 0,5 | 0,5 |
| Reflectance floor cavity | 0,2 | 0,2 | 0,2 |
| annual operating hours(ref) | 2250 | 2250 | 2250 |
| ηballast (T8 corrected for HF operation) | 1,03 | 0,9 | 0,9 |
| BGF (ballast gain factor) | 1 | 2,26 | 2,26 |
| ηlamp (lm/W) (T8 on magnetic) | 93,06 | 120,00 | 103,00 |
| LLMF (lamp lumen maintenance f) | 0,90 | 0,70 | 0,90 |
| **luminaire type** | **reflector** | **LED** | **reflector** |
| CIE flux code N1(41,4°) | 0,76 | 0,79 | 0,65 |
| CIE flux code N2(60°) | 0,99 | 0,99 | 0,99 |
| CIE flux code N3(75,5°) | 0,99 | 0,99 | 0,99 |
| CIE flux code N4(DFF) | 1,00 | 1,00 | 1,00 |
| CIE flux code N5(LOR) | 0,66 | 1,00 | 0,90 |
| LMF | 0,85 | 1,00 | 0,80 |
| LER (functional lumen/W) | 63,3 | 108,0 | 83,4 |
| RSMF | 0,96 | 0,96 | 0,96 |
| U (utilance) | 0,84 | 0,86 | 0,79 |
| LPDi (W/(m².100lx) or W/100 f-lm) | 2,55 | 0,71 | 0,98 |
| LENI (kWh/(m².y) | 5,74 | 1,60 | 2,20 |

**Conclusion:**

This office lighting example illustrates that the energy consumption per year and per useful lumen, when comparing the Worst Case projected for 2017 with the BAT, can drop from 5.74 kWh/(m².y) to 1.60 kWh/(m².y), **i.e. an energy saving of 62 %**.

The main improvement comes from control systems in conjunction with a higher LER for the LED luminaire. More refined analysis will be done in later tasks 4-6.

#### *1.6.5.10 Reference Worst Case (WC) 2020 compared to BAT 2020 related to changing domestic luminaire design (indoor)*

In domestic lighting and some other similar lighting applications there are no strict illumination requirements imposed via standards, as opposed to typical non-domestic lighting applications. This has an impact on the functional unit (see Task 1) and therefore also on system improvement options.

In the Preparatory Study for Domestic Lighting, several improvement options were discussed at 'system level' that can also be applied in other lighting applications. Note: in Lot 19 the luminaire was part of the system environment.

Improvement options related to lamp efficacy improvements:

- avoid the lock-in effect into low efficiency lamps of class C or lower;
- design luminaires that create a positive lock-in effect into efficient lighting;
- use coloured LEDs to create coloured light.

Options for the design of luminaires with appropriate and efficient control electronics:

- luminaires that incorporate or are compatible with dimmers;
- luminaires with motion sensors incorporated where appropriate;
- outdoor luminaires with day/night sensors incorporated;
- eliminate standby losses when power supplies are incorporated in luminaires;
- use electronic control gear instead of magnetic (conventional) control gear for CFLni and low voltage halogen.

Options to increase the optical efficiency of luminaires:

- use material with increased light transmittance for visible parts that are transparent / translucent;
- use materials with increased reflectance for invisible parts that are not transparent/translucent;
- use the correct category of luminaire for the correct application and provide appropriate user information.

Other luminaire related improvement options:

- design outdoor luminaires with photovoltaic panels;
- use a reflector lamp or an LED-luminaire instead of a luminaire with reflector for downlighters.

**Conclusion:**

Annex I of lot 19 included estimates on Luminaire improvement options **which can results in cumulative savings up to 80 %,** on the assumption that they are all relevant and applicable. More refined analysis will be done in later tasks 4-6.

#### *1.6.5.11 Reference Worst Case (WC) 2020 compared to BAT 2020 for the building energy balance related to lighting*

As shown in sections 0.4 and 1.3.3, lighting systems are specified by different characteristics. Taking into account all these characteristics makes it difficult to compare different lighting systems. When looking at lighting systems within the context of a whole building energy performance approach, this becomes even more difficult, since windows also need to be considered.

Windows are generally the weakest link in the building envelope from an insulation point of view (e.g. U=0.24 W/m²K for walls and roofs versus 1.1 W/m²K for windows), but provide natural daylight and solar heat gains. Heat losses and solar heat gains, as well as daylight provision are all characterized by different aspects of the window and its surroundings (e.g. shades, etc.).

Daylight is considered a crucial aspect in sustainable building, as shown by the BREEAM rating system, where in the section of health and well-being credits can be awarded for daylit rooms.

Also, windows play an important role in the perception of space and often contribute to the architectural qualities of a building, especially in office buildings.

**Conclusion:**

**There is no ready to use data for the quick scan, however the impact of modelling is included in standard DIN EN 15232:2007-11, and therefore it is recommended to reconsider this in the subsequent tasks.**

### 1.6.6 Input received from field experience of lighting designers on target application area's

Note the following input was received from IALD[23]:

“Typically Hospitals and public education establishments are designed with a high priority placed on energy efficiency in lighting. It is challenging that the proposed energy savings would be achieved by regulation as these are already being designed in for new build and refurbishment projects. Commercial developments, office and retail show the largest opportunity for system level savings as prime cost rather than cost in use drives these projects. Hotels and Restaurants require lighting system design to focus on the aesthetic qualities of light with style and fashion dictating much of the design trend. Systems regulation on maintenance and operation would be most effective here.”

### 1.6.7 Conclusions on scope

As already can be concluded, savings at system level can be very significant and can reach up to 90% when comparing the worst case implementation permitted according to the existing legislation after 2017 with the best available techniques.

Therefore the statement made in a working document of the consultation of September 2010 on lighting is still a realistic estimate; it states that ‘addressing lighting at system level would contribute to 90 TWh[80] for the whole non-domestic sector’[81]. Of course, all TWh consumed in lighting can only be saved once. This means that when light sources become more efficient, the total impact from other system related improvement options will become proportionally less. Subsequent tasks will analyse this in more detail, with more categories, more representative base cases and consider more improvement options.

The estimated energy consumption (2007) per sector and rough first estimates of the maximum savings found are summarised in Table 1-17 and Table 1-18. The findings in

[80] Of Annual Energy Savings in lighting installations (2005 reference)
[81] The 90TWh refers to estimated annual energy savings in 2020

these tables imply that the remaining tasks should specially focus on indoor lighting systems in the sectors of: education, hotel & restaurants, hospitals, retail, offices, sports and industry. For outdoor lighting the focus should be on street lighting and the public & recreational sector. In task 2 the screening of application areas will continue and might reveal new areas of importance. Also lighting designers pointed out that interesting application areas are commercial developments, office and retail.

*Table 1-17: Annual indoor lighting energy consumption per sector and maximum savings identified*

| sector | TWh | saving up to % |
|---|---|---|
| **Education** | 17,2 | 70% |
| **Hotels & restaurants** | 23,5 | 70% |
| **Hospitals** | 20,3 | 70% |
| **Retail** | 47,3 | 70% |
| **Offices** | 29,0 | 70% |
| **Other** | | 70% |
| **other (% sports)** | 18,0 | 70% |
| **other (% industry)** | 18,0 | 70% |
| **other (% any other)** | 4,6 | NA |
| **households** | 82,0 | 80% |

*Table 1-18: Annual outdoor lighting energy consumption per sector and maximum savings identified*

| sector | TWh | saving up to % |
|---|---|---|
| public lighting | 40,1 | 90% |
| industry sector outdoor | 6,2 | 90% |
| service & recreational sector | 16,9 | 90% |
| households | 2,1 | 90% |
| agriculture green houses | 6,8 | unknown |
| Total outdoor | 72,0 | |

# CHAPTER 2 Markets

**The Objective**

The objective of Task 2 is to present an economic and market analysis of lighting system products. The aims are:

- to place the lighting system products within the context of EU industry and trade policy (subtask 2.1);
- To provide market size and cost inputs for the EU-wide environmental impact assessment of the product group (subtask 2.2);
- To provide insight into the latest market trends to help assess the impact of potential Ecodesign measures with regard to market structures and ongoing trends in product design (subtask 2.3, also relevant for the impact analyses in Task 3); And finally,
- To provide a practical data set of prices and rates to be used for Life Cycle Cost (LCC) calculations (subtask 2.4). It should be noted that price informationis also be supplied within Task 4.

**Summary of task 2:**

The preparatory phase of this study is to collect data for input from stakeholders. A final summary of this task will be elaborated during the completion of the final report.

The European lighting market data and later on in Task 7 the high-level (scenario) energy impact analyses of this study will be linked to the 'Model for European Light Sources Analysis' (MELISA), that has been developed in the Ecodesign preparatory study on Light Sources. It is important to understand the differences in approach and scope between those studies, In MELISA, the initial lighting capacity, useful lifetime sales and stock volumes are expressed in quantities of light sources and not luminaires. The scope of this study as defined in Task 1 is on lighting installations that are designed to fulfil lighting design requirements according to standards EN 12464 for indoor lighting and EN13201 for outdoor lighting. As a consequence a lighting design will require a set of luminaires for each specific application. The MELISA model was therefore extended with several parameters to enable it to interface between both studies. This will be useful should Task 5 and 6 assessments be needed to estimate the total impact across Europe of different lighting system designs and their improvement options. In this study the 'product' is lighting installations and their designs. This means that the typical market product unit driver is floor or road surface area. Market data on these areas is included in this task report. Because the outcomes of lighting design energy evaluations of such systems are given in kWh/y.m², see Task 1, these values can together with surface area be cross-checked or verified with MELISA data based on light source energy consumption. For non-residential applications there is a good alignment.
More details on typical lighting applications within the scope of this assessment and their requirements are given in Task 3 on Users. Typical lighting solutions for these applications are discussed in Task 4. A more refined market analysis has also been conducted to determine which typical task areas and/or building applications consume significant amounts of energy. This showed that in addition to office spaces the lighting energy consumption in circulation area's, manufacturing area's, toilet rooms, storeroom/warehouses and shops is also significant.
When conducting the analyses using the MELISA model and later Tasks 5-7 it will be important to avoid double counting the effect of increased lamp efficacy within lighting stock energy consumption scenarios, because they are already taken into account in the light source study. Therefore, when defining so-called base cases for the system study they should already have this efficacy increase included. It is expected that this modelling can be done by adding reference designs with lamp efficacies in line with

the light source study scenarios applied in MELISA and by rescaling the base cases in Task 5 and improvement options in Task 6 accordingly.
This study builds on the previous office lighting and road lighting study but when defining reference applications in Task 4 it could be worth considering other applications that have significant impact. This will be discussed in the stakeholder meeting.

Comment: This report is currently a work in progress, as some parts of the study have not yet received the benefit of comments and data from stakeholders, therefore it should not be viewed as a draft final report.

## 2.1 Model for European Light Sources Analysis (MELISA)

### 2.1.1 Introduction to the MELISA model

The 'Model for European Light Sources Analysis' (MELISA) has been developed in the Ecodesign preparatory study on Light Sources (Lot 8/9/19) [82]. This study was performed in parallel to the Lot 37 Lighting Systems study and was concluded in October 2015.
The MELISA model has been developed on request of the European Commission with the aim to harmonize the data for the two related preparatory studies on lighting. Consequently the data and calculation methods contained in this model will form the basis for the high-level (scenario) analyses in the Lighting Systems study. The final version as described in the Task 7 report of the Light Sources study will be used.

MELISA distinguishes the light source base cases presented in Table *2-1*. There are five groups of light source types: Linear Fluorescent Lamps (LFL), High-Intensity Discharge lamps (HID-lamps), Compact Fluorescent Lamps without integrated ballast (CFLni), Directional lamps (DLS) and Non-directional lamps (NDLS). As shown in the table, each group is further subdivided in classical technology base cases and also has two associated LED base cases, respectively for LED retrofit lamps and integrated LED luminaires. The shift in sales from the classical technology base cases to the LED base cases of the same group is one of the essential elements in the scenario projections in MELISA [83].

Although not shown in the table, all data in MELISA (both input data and calculated results) are subdivided in those related to the residential sector and those related to the non-residential sector. This is important for the Lighting Systems study because the scope in Task 1 has been limited to EN 12464 indoor work places and EN 13201 road areas.

MELISA derives the installed stock of light sources in the EU-28 from data on the annual sales and on the average useful lifetimes (of light sources). These stock data are combined with average unit power values (W) and average annual operating hours per unit (h/a) to compute the total electricity consumption per base case (TWh/a). The contributions of the various base cases are summed to get the EU-28 totals per sector (residential, non-residential) and the sum of the latter two provides the overall EU-28 total for all sectors. Greenhouse gas (GHG) emissions are directly related to electricity consumption.

[82] http://ecodesign-lightsources.eu/documents
[83] For details see the Task 7 report of the Light Sources study.

The electricity consumption is multiplied by the electricity rates (euros/kWh, fixed 2010 euros, discount rate 4%) to compute the associated annual electricity costs (bn euros per year). These are combined with the annual maintenance costs to obtain the total annual running costs.

The light source base cases distinguished in the MELISA model and the improvement options considered in the policy scenarios of Task 7 of the Light Sources study are shown in Table *2-1*. The base cases are organized into five application groups (LFL, HID, CFLni, DLS and NDLS). Within each application group there are classical technology base cases (shown on the left) and base cases for LED lighting products that can replace the classical products in the same application (shown on the right). LED products are subdivided in retrofit solutions and integrated LED luminaires. Light source sales data in Annex B are organized according to these five application groups and their base cases.

Multiplying the annual sales by unit prices per light source provides the purchase costs (per base case, per sector, and the overall EU-28 total). Adding the installation costs provides the total acquisition costs, per sold light source.
The sum of acquisition costs and running costs is the total consumer expense.

A survey of the main input variables and the calculated intermediate and final results for MELISA is provided in Table 2-2. For further details see the Light Sources study [82], in particular the Task 2 (sales, stock), Task 3 (light source usage parameters), Task 4 (summary of input data per base case) and Task 7 (BAU and ECO scenarios) reports.

All economic data in MELISA are in fixed 2010 euros and include 20% VAT for the residential sector, and no VAT for the non-residential sector.
The input data and the output data of MELISA were extensively checked against other sources and also discussed with stakeholders in the course of the Light Sources study [84]. In particular, the sales data are based on a mix of data from the industry association LightingEurope, Eurostat and GfK market research.

For the residential sector the data are considered to be fairly accurate, within a maximum estimated error of 10%. For the non-residential sector some data could have a larger error, in particular with respect to the average annual operating hours and the sales volumes of HID-lamps.

The MELISA data are therefore considered to be a sound basis for the analyses to be conducted in the Lighting Systems study.

[84] See the Task 2, 3 and 4 reports of the Light Sources study.

Table 2-1 Light source base cases distinguished in the MELISA model (left hand side) and improvement options used in scenarios (right hand side)

| Base cases | Improvement options |
| --- | --- |
| **LFL T12**<br>**LFL T8 halo-phosphor (T8h)**<br>**LFL T8 tri-phosphor (T8t)**<br>**LFL T5 (new 14-80 W) incl. circular**<br>**LFL other (old T5 ≤ 13 W, special FL) (LFL X)** | **LED Retrofit lamps for LFL replacement**<br>**Integrated LED luminaires for LFL applications** |
| **High-Pressure Mercury (HPM)**<br>**High-Pressure Sodium (HPS)**<br>**Metal Halide lamps (CMH, QMH)** | **LED Retrofit lamps for HID replacement**<br>**Integrated LED luminaires for HID applications** |
| **Compact Fluorescent Lamps without integrated ballast (CFLni)** | **LED Retrofit lamps for CFLni replacement**<br>**Integrated LED luminaires for CFLni applications** |
| **Halogen Low-Voltage mirrored (HL LV R)**<br>**(MR11, MR16, etc. GU4, GU5.3 caps)**<br>**Halogen Mains-Voltage reflector (HL MV X)**<br>**(R-lamps, PAR-lamps, etc., GU10 or E-cap)**<br>**Incandescent reflector lamps (GLS R)** | **LED Retrofit lamps for DLS replacement**<br>**Integrated LED luminaires for DLS applications** |
| **Halogen LV capsules (HL LV C) G4, GY6.35 cap**<br>**Halogen MV capsules (HL MV C) G9 cap**<br>**Halogen MV, GLS substitute (HL MV E) E-cap**<br>**Incandescent non-reflector (GLS X)**<br>**Compact Fluorescent Lamps with integrated ballast (CFLi)**<br>**Halogen MV linear (HL MV L) R7s-cap** | **LED Retrofit lamps for NDLS replacement**<br>**Integrated LED luminaires for NDLS applications** |

*Table 2-2 MELISA input data and calculated intermediate and final results (for every base case, for the residential and the non-residential sector)*.*

| Model Input data (per BC) | Intermediate results | Output data (EU-28 total) |
|---|---|---|
| Sales in EU-28 per year | Stock in EU-28 per year | |
| Avg. useful lifetime (hours) | Avg. useful lifetime (years) | |
| Avg. annual operating hours (h/a) | | EU-28 total installed capacity (Tlm) |
| Avg. unit capacity (lm) | Avg. unit power (W) | EU-28 total installed power (GW) |
| Avg. sales efficiency (lm/W) | Avg. stock efficiency (lm/W) | Electric Energy (TWh/a) |
| Avg. unit price (euros) → | → | |
| Taxes (VAT 20% residential) | Purchase costs (billion euros) | |
| Avg. unit install cost (euros) | | Acquisition costs (billion euros) |
| Electricity rates (euros/kWh) | Electricity costs (billion euros) | |
| Escalation rate (4% /a) | | Running costs (billion euros) |
| Avg. unit maintenance (euros/a) | | Total consumer expense (bn euros) |

*For the formulas used in the calculations, see the Task 2 and 7 reports of the Light Sources study.

### 2.1.2 MELISA details relevant for the Lighting Systems study

#### *2.1.2.1 Sales and stock volumes and sales factor 'Fsales'*

All sales and stock volumes in MELISA are expressed in quantities of light sources. Even the quantities of integrated LED luminaires in reality represent the quantity of LED light sources contained in these luminaires, and this quantity is derived using a one-to-one substitution of the classical technology light sources by LED light sources.

This approach has consequences for the use of the model in the Lighting Systems study where the reasoning is often in terms of quantities of luminaires instead of quantities of light sources. The number of light sources per luminaire and the difference between light source lifetime and luminaire lifetime should therefore be adequately taken into account.

Improvements in the design of lighting systems can lead to a reduction of the number of installed light sources, e.g. by optimising the lighting layout in a room, optimising the luminaire optical characteristics and optimising the surface reflections it may be possible to install less light sources than before and still obtain the required illuminance in the task- and surrounding areas.
Lighting system optimisation could also lead to an increase of the number of light sources in a room or building space. For example local task lighting points could be added on office desks while decreasing the installed capacity (lm) of the (uniform) general ambient office lighting (less light sources or less lumens per light source or a combination of these) [85].
In these cases the light source substitution is no longer one-to-one but less, and the actual sales will be lower or higher than the potential sales. This lighting systems effect can be expressed in MELISA by means of the **sales factor 'Fsales'**. The application of this factor is further explained in the example of Table 2-3.

[85] This practice is indicated by IALD as an energy saving option and would also increase flexibility when the use of the room is reorganized: just move the local desk lighting while leaving the general lighting the same.

In order to determine the factor Fsales, the Lighting Systems study has to derive or estimate:

- The **share Ps,inv** [86] of the EU-28 total sales for a base case application for a given year that is involved in a lighting system design optimisation leading to a change of the number of installed light sources and consequently to a change in sales. The current (2015) reference share is set to zero, which is also the value assumed in the Light Sources study for all years (Ps,inv =0% → Fsales =100%).
  - 
- For the share Ps,inv , the quantity of light sources remaining after the optimisation, expressed as the **share Ps,rem** [86] of the quantity of light sources that were installed before the optimisation [87]. The current (2015) reference share is set to 100%, which is also the value assumed in the Light Sources study for all years (Ps,rem =100% → Fsales =100%)
  - 
- **Fsales = 100% – Ps,inv * (100% – Ps,rem)** (see example in Table 2-3)

The factor can be set separately for each base case and for the residential and non-residential sectors of that base case.

*Table 2-3 Example (for sales related to LFL T8t in 2015) of the application in MELISA of the sales factor Fsales to account for the effect of the reduction of the number of light sources due to improvements in lighting system design.*

Derivation of the 2015 sales related to LFL T8 tri-phosphor light sources:

| | | |
|---|---|---|
| Lamps reaching end-of-life: | 168 mln | (based on sales in 2009 and lifetime 6 years) |
| Lamps for new applications: | 32 mln | (based on stock in 2014 and annual growth rate) |
| Lamps substituting T12/T8h: | 21 mln | (taken from the LFL T12 and LFL T8h base cases) |
| Potential LFL T8t sales: | 221 mln | (sum of the above) |

These potential sales are distributed in MELISA as actual sales according to a scenario (BAU or ECO), for example:

| | | |
|---|---|---|
| Share remaining LFL T8t: | 188 mln (85%) | (shares vary from year to year |
| Shifting to LFL T5: | 22 mln (10%) | and from scenario to scenario, |
| Shifting to LED retrofit: | 8 mln (3.5%) | with LED share increasing in |
| Shifting to LED luminaire: | 3 mln (1.5%) | later years) |

Each of these sales quantities is multiplied (on the Excel sheet for the corresponding base case) by a factor, Fsales, which by default is 1.0.

If e.g. we assume (on the level of EU-28 as a total) that in Ps,inv = 20% of the cases the light sources shifting to LED luminaires will be involved in an optimised lighting system design and that this optimisation permits the number of light sources to be reduced to Ps,rem=75% of the original quantity, the actual number of light sources inside LED luminaires sold in 2015 would become (100%-20%)*3 mln + 20%*75%*3mln = 2.85 mln. So the factor to be applied on the LED luminaire sheet would be Fsales = 2.85/3 *100% = 95%, or Fsales = (100%-Ps,inv) + Ps,inv*Ps,rem = 100%-Ps,inv*(100%-Ps,rem) = 100%-20%*(100%-75%) = 95%.

[86] Ps,inv = Percentage, sales, involved; Ps,rem = Percentage, sales, remaining
[87] The name 'remaining' suggests a reduction of the number of light sources, and this is expected to be the most frequent case, but as explained in the text in some cases there could also be an increase in the number of light sources due to the system optimisation. In those cases Ps,rem can also be larger than 100%.

### 2.1.2.2 Power, capacity, operating hours and factors Fphi and Fhour

**The lighting capacity (expressed in lumen, lm) in MELISA is the initially installed (rated) capacity at 100 h operation of the light source (NOT of the luminaire).** It is divided by the initial (rated luminous efficacy (expressed in lm/W) in standard testing conditions to obtain the initially installed (rated) full power of the light source.
The value chosen for the initial installed capacity already reflects that it may have been chosen to be higher than strictly necessary, to compensate for lumen degradation with time, or for lower efficacy at operating temperatures, or because the exact desired lumens were not available.

For light sources with integrated ballast or control gear, their efficacy includes the efficiency of the ballast/gear and consequently the derived power is the combined power for light source and ballast/gear together. In these cases the efficiency of the ballast/gear is set to 100% in the model.

For light sources with external ballast or control gear, the light source efficacy and power are considered separately from the ballast/gear efficiency and power.

It is essential to note that capacity, efficacy and power in MELISA are always initial, full, rated values (they are NOT average values over the lifetime).

To compute energy consumption, the full power is multiplied by the average full-power-equivalent operating hours per year. This means that effects of dimming are being accounted for in the equivalent operating hours (and NOT in the power). For example, if a light source is operated at full power for 1500 hours per year, at 50% power for 500 h/a and at 25% power for 200 h/a, the full-power equivalent hours to be considered in MELISA would be 100%*1500 +50%*500+25%*200 = 1800 h/a [88]. If dimming changes over the years, for example to compensate for lumen degradation, the average annual hours over the lifetime should be considered [89]. The only criterion for the determination of the hours is that, when multiplied by the full rated power, the correct average annual energy consumption over the lifetime results.

For all classical technology base cases MELISA defines the average unit capacities, average light source efficacies and average annual operating hours per unit (full-power equivalent). When these classical technologies are substituted by LED lighting products, the latter inherit the capacities and the annual operating hours of the former, but a (small) rebound factor is applied [90]. In principle, all these parameters already defined in MELISA should NOT be changed in the Lighting Systems study because they form the common harmonized data for both lighting studies. MELISA has two separate factors, Fphi and Fhour, to express the effects of lighting system improvements.

[88] The % power during dimming should be used as the weighting factor, NOT the % of emitted luminous flux.
[89] If e.g. lumen maintenance is 70% at end of useful life, and continuous constant illuminance dimming is applied to compensate for lumen degradation, dimming at start of life will be to 70% of rated power and at end of life to 100% of rated power, so average to 85%. Consequently, average annual operating hours have to be multiplied by 90%.
[90] In general this factor accounts for the fact that consumers have the tendency to buy higher lumen lamps and to let them burn longer when the light sources are more energy efficient. The same factor could also be used to implement other changes in capacity. For example when low CRI HPS lamps are substituted by higher CRI LED it is probably possible to install less LED lumens than the HPS lumens before. In some LFL applications the directionality of LED tubes also allows to reduce the installed lumens. (assumption from VHK made in MELISA)

The **factor Fphi** (expressed as a percentage) can be used in the Lighting Systems study when improvements in lighting system design (layout, luminaire design, surface reflections) lead to the installation of less capacity (lumen) in a room or building space than before (while maintaining the same number of light sources, see Fsales before).
In order to determine the factor Fphi, the Lighting Systems study has to derive or estimate:

- The **share Pf,inv** [91] of the EU-28 total flux for a base case for a given year that is involved in a lighting system design optimisation leading to a reduction of the installed luminous flux. The current (2015) reference share is set to zero, which is also the value assumed in the Light Sources study for all years (Pf,inv =0% → Fphi =100%).
- For the share Pf,inv , the installed luminous flux remaining after the optimisation, expressed as the **share Pf,rem** [91] of the flux that was installed before the optimisation. The current (2015) reference share is set to 100%, which is also the value assumed in the Light Sources study for all years (Pf,rem =100% → Fphi =100%)
    - 
- **Fphi = 100% – Pf,inv * (100% – Pf,rem)**

The factor can be set separately for each base case and for the residential and non-residential sectors of that base case.

The **factor Fhour** (expressed as a percentage) can be used in the Lighting Systems study when improvements in lighting system design (installation of dimmers, timers, daylight sensors, occupancy sensors, constant illuminance controls, etc.) lead to lower average annual operating hours (full-power equivalent) than before.
In order to determine the factor Fhour, the Lighting Systems study has to derive or estimate:

- The **share Ph,inv** [92] of the EU-28 total operating hours for a base case for a given year that is involved in a lighting system design optimisation leading to a reduction of the annual operating hours. The current (2015) reference share is set to zero, which is also the value assumed in the Light Sources study for all years (Ph,inv =0% → Fhour =100%).
- For the share Ph,inv , the annual operating hours remaining after the optimisation, expressed as the **share Ph,rem** [92] of the operating hours before the optimisation. The current (2015) reference share is set to 100%, which is also the value assumed in the Light Sources study for all years (Ph,rem =100% → Fhour =100%)
- **Fhour = 100% – Ph,inv * (100% – Ph,rem)**

The factor can be set separately for each base case and for the residential and non-residential sectors of that base case.

**Important conclusions for any later Tasks 5-7:**
**It will be important to avoid double counting of increased lamp efficacy in scenarios on projected energy consumption of the lighting stock, because this is already taken into account in the light source study. Therefore, when defining the base case" for the system study this base case should already include these efficacy increases. It is expected that this modelling can be done by adding reference designs with lamp efficacies in line with MELISA and rescale the base cases in Task 5 and improvement options in Task 6 accordingly**.

[91] Pf,inv = Percentage, flux, involved; Pf,rem = Percentage, flux, remaining
[92] Ph,inv = Percentage, hours, involved; Ph,rem = Percentage, hours, remaining

### 2.1.2.3 Cost information limitations

MELISA only includes the price information that was necessary in the Light Sources study, i.e. unit purchase prices, unit installation costs and annual unit maintenance costs are all for light sources and are multiplied by light source sales and stock quantities to compute EU-28 totals.

Costs for luminaires, control gear and ballasts for classical technology lamps are not currently considered in MELISA, except for light sources with integrated gear where gear costs are obviously included in the unit price for the light source.

For LED lighting products the unit prices include all hardware that is necessary to make the products operational (new starters, control gears, any new wiring), but in the Light Sources study the same prices were used for LED retrofit lamps and integrated LED luminaires, even if for the latter base cases (and only for these) MELISA offers the possibility to define additional LED luminaire costs and installation costs [93].
Costs of control devices, network-communications, timers, dimmers, daylight sensors, occupancy sensors, system installation, management and maintenance costs, etc. are not foreseen in MELISA.

The factors Fsales, Fphi and Fhours are sufficient to predict the energy savings and GHG emission reductions due to improved lighting systems. The same factors will also have several cost saving effects:

- Fsales leads to lower sales and hence lower purchase and installation costs for the light sources. Lower sales also means lower stock and hence lower energy costs and lower maintenance costs for the light sources

- Fphi leads to lower installed capacity, hence lower installed power, lower energy and lower energy costs. For LED lighting products, where the purchase price is expressed in euros/klm, lower capacity also means lower purchase costs

- Fhour leads to lower operating hours, hence lower energy consumption and lower energy costs

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[93] This feature might be used in future in the Impact Assessment for Light Sources to study the effect of additional luminaire and installation costs in a sensitivity analysis. Great caution is necessary when defining these costs, because:

1) The costs will be multiplied by sales volumes of light sources, not by the sales volumes of luminaires.
2) The costs of the LED retrofit light sources are already taken into account and should not be counted again with the LED luminaire.
3) The costs of classical technology luminaires are not accounted in the model, so only the difference in costs between classical luminaires and integrated LED luminaires should be counted, unless a consumer is really forced to buy an integrated LED luminaire before the end of life of the classical technology luminaire. In that case the remaining worth of the classical luminaire should be considered.
4) LED prices are expressed in MELISA in terms of euros/klm and a single average price is used for all lamp types. The impression is that this average might be too high for high-lumen lamps as LEDs substituting LFLs and HID-lamps, that are of main interest for the Lighting Systems study. So current LED costs in MELISA could already be overestimated for these lamp types.
5) In some cases the 'additional costs' to be considered might also be negative.

However the additional investments in lighting systems that have to be made to obtain the above energy and cost savings are currently not included in MELISA. What is missing:

- Additional costs for the design, installation, operation and maintenance of the lighting system as a whole.
- Costs of control devices, network-communications, timers, dimmers, daylight sensors, occupancy sensors, etc.
- Additional costs for new control gears / ballasts (controllability, dimmability)
- Additional luminaire costs

There are two options to address these costs in future analyses:

- Change the existing MELISA purchase, installation and maintenance costs and use the option to add additional costs for the integrated LED luminaires. These costs should then be scaled in such a way that multiplication by the light sources sales or stock produces the correct totals. This might be rather complicated and confusing

- Use a separate accounting system of additional costs and sum this a posteriori with the MELISA values. This might be easier and more transparent [94]. This option is preferred because of the complications inherent in the previous option.

**Important conclusions for any later Tasks 5-7:**
**In the lighting system a separate cost accounting will be done based on cost data supplied in Task 4 for the several design options (worst case, BAT, ..) for lighting applications defined in Task 3. For the total EU cost impact analysis the system study data might be rescaled to MELISA in future Tasks 5 to 7.**

### 2.1.3 Determination of MELISA's system parameters

As explained in section 2.1.2, the following percentages have to be defined in the Lighting Systems study, separately for each base case and separately for the residential and non-residential sector:

- Ps,inv: share of total EU-28 sales of light sources involved in sales reduction
- Pf,inv: share of total EU-28 installed capacity (lm) involved in flux reduction
- Ph,inv: share of total EU-28 operating hours (fpe h/a) involved in hour reduction

- Ps,rem: share of involved sales remaining after system optimisation
- Pf,rem: share of involved luminous flux remaining after system optimisation
- Ph,rem: share of involved operating hours remaining after system optimisation

#### Ps,inv, Pf,inv, Ph,inv

The 'involved' shares express the degree of penetration of improved lighting systems in the EU-28. They would be expected to slightly increase with time (BAU scenario) and there could be an acceleration after the introduction of an ecodesign measure

[94] This separate accounting can be outside of MELISA or can be added to the MELISA Excel sheet.

(ECO scenario) [95]. The degree of penetration would also be expected to be higher for modern more efficient light source types such as LEDs than for classical technology types. The current (2015) situation is taken as reference, with Ps,inv, Pf,inv and Ph,inv all set to 0%.

The 'involved' shares should be determined based on trends in lighting system 'sales' and on trends in the type of systems installed (i.e. influence is on sales, flux or hours). This type of information can probably only be provided by professionals working in the sector, any information from stakeholders is welcome ).

**Indicative methods for estimating Ps, rem and Pf, rem should be defined in Tasks 5 and 6 based on the parameters calculated in Task 4.**

## 2.2 Generic economic data

### 2.2.1 Introduction

The aim of 'Generic economic data' according to the MEErP (Annex A) is to give an overview, for the product group that is the subject of the Ecodesign preparatory study, of production and trade data as reported in the official EU statistics. The apparent product sales (=production +import -export) can be derived from these data.

Lighting Systems are designed, sold, installed, commissioned, operated and maintained and as such they are 'products', but they are not actually produced [96], shipped, imported or exported as a whole sytem. Consequently they are not distinguished as a product in the Eurostat production and trade statistics (Europroms-PRODCOM) [97].

**The scope of this study as defined in Task 1 is on lighting systems or installations that are designed to fulfil lighting design requirements according to standards EN 12464 for indoor lighting and EN13201 for road lighting. As a consequence a lighting design will require a set of luminaires for each specific application. This also means that the most appropriate l market product unit is the floor or road surface area of lighting installations. Such data can be found in European statistics. Because EN 12464 and EN 13201 are not applicable to residential applications they are excluded from the market data. It should be noted that not all type of non-residential area is covered by EN 12464 and EN 13201, see Task 1.**

As explained before, the preferred market data approach used in this lighting system study is to start from the number, sizes and types of buildings in the EU-28, from the types of spaces in these buildings, and from the number, size/length and types of roads and (possibly) other outdoor spaces. This information allows the estimation of the potential number of Lighting Systems, in relation to the types of spaces and activities. This approach was also followed in the preceding preparatory studies on office and street lighting[98].

[95] An ecodesign measure can prescribe minimum product performance parameters, so the main effect would expected to be on Ps,rem , Pf,rem and Ph,rem. The ecodesign measure cannot prescribe that more consumers have to install efficient lighting systems.
[96] It could be stated that they are assembled 'on-site'
[97] http://epp.eurostat.ec.europa.eu/newxtweb/ . There is a NACE rev.2 code 4321 for electrical installations that also comprises 'lighting systems installation' but these activities are not included in the production and trade statistics of PRODCOM.
[98] http://www.eup4light.net/

Such information is also necessary for the estimation of factors such as the EU-28 total energy savings due to lighting system improvements from a series of possible savings computed by the study team for individual base cases (cellular offices, open-plan offices, shops, high-ways, parking lots, etc.): each base case saving has to be multiplied by the number of such base case spaces in the EU-28 (or by an assumed share thereof).

Trade data and apparent sales could be derived from Eurostat data for some of the components of Lighting Systems, in particular for light sources, ballasts/control gear and luminaire,s and thus could also contribute to provide market insights into installed lighting systems. For other components such as sensors, controls, dimmers, communication electronics (WiFi, Zigbee, DALI, etc.), and wiring this is more difficult.

Even if trade and sales data on the components were to be available, it is not an easy task to derive the number of Lighting Systems installed in the EU-28, because this would require knowledge of the average number of components in such a system.

The following paragraphs will first examine what trade and sales data are available for Lighting System components (not necessarily only drawn from Eurostat data). Next, the number, sizes and types of buildings, roads and spaces are examined.

### 2.2.2 Sales and stock of light sources

The EU-28 total sales and stock of light sources have been extensively reported in Tasks 2 and 7 of the Light Sources study [82]. These sales volumes are based on a mix of data from the industry association LightingEurope, from Eurostat and from GfK market research data. Additional data that could be relevant for the Lighting System study and that have not been reported in the Light Sources study are included in Annex C. This annex provides the sales and the stock for the period 1990-2030, for all base cases, subdivided into the residential and non-residential sector, and organized per application group (LFL, HID, CFLni, DLS, NDLS). These data are for the BAU-scenario as defined in Task 7 of the Light Sources study [99].

It can be concluded from these data that LFL T12, LFL T8 halo-phosphor, HPM-lamps, GLS-lamps and most mains-voltage halogen lamps (except those with G9 and R7s caps) need not be considered in the study because by 2020 they are no longer sold and their stock is negligible or zero.

A second conclusion from these data is that classical technology lamp types are increasingly being substituted by more efficient LED lighting products. Consequently, the focus in the study should be on the use of LED light sources.

### 2.2.3 Sales of ballasts and control gears

Eurostat trade and sales data for magnetic and electronic ballast are presented in Annex D. These data can be summarised as follows:

- In 2013 around 600 million magnetic ballasts were sold in EU-28, representing a total value of around 165 million euros, for an average value of 0.27 euros/ballast.
    - No clear trend in sales can be identified.

[99] That scenario includes the future effects (phase-outs) of current lighting regulations, i.e. 244/2009 stage 6 (mains-voltage non-directional halogen lamps), 1194/2012 stage 3 (mains-voltage directional halogen lamps), and 245/2009 stage 3 (more severe requirements for MH-lamps and for external ballasts), and also includes the expected trend in substitution of classical technology lamp types by LED lighting products.

- In 2013 around 70 million electronic ballasts were sold in EU-28, representing a total value of around 550 million euros, for an average value of 8.11 euros/ballast.
    - As regards sales quantities there is a downward trend, from 150 million units in 2006-2007 to 70 million units in 2013.

For several reasons, these Eurostat data are puzzling and remainunreliable [100]:

- The total number of ballasts sold in 2013, around 670 million units, is high compared to the number of LFL, CFLni and HID lamps sold (around 450 million), in particular when considering that one ballast often controls more than one lamp and that ballast useful lifetime is typically longer than the light source lifetime.

- According to the Eurostat data the share of electronic ballasts would be around 10%. However, this is contrary to expectations, contrary to trends elsewhere in the world (approximately 80% electronic in Australia and Canada; 75% electronic in the USA in 2005) and contrary to CELMA information from 2010 (see below) that gave 45% electronic ballast sales share in Europe in 2008 with an increasing trend.

- An average magnetic ballast would be expected to weigh not less than 0.5 kg, which, based on the Eurostat data, would imply a value of around 0.50 euros/kg or less. This looks more like a scrap-value than a value for a new product being sold.

In a 2010 publication [101], CELMA & ELC (now LightingEurope) provide the annual numbers of new installed lamps driven by a given type of ballast, for the period 1997-2008 with a forecast up to 2010, separated into LFL and HID-lamps:

- For linear fluorescent lamps, 221 million ballasts were sold in 2008, of which 48% were electronic. The prediction for 2010 was for a share of at least 62% for electronic ballasts (Figure 2-1).

- For high-intensity discharge lamps, 20 million ballasts were sold in 2008, of which 33% were electronic. The prediction for 2010 was for a share of 41% for electronic ballasts (Figure 2-2).

The 2010 CELMA&ELC data are considered to be more reliable than the Eurostat data and will therefore be preferred for the analysis. Extrapolating these data, it is estimated that currently (2015) 75-80% of the ballasts sold for fluorescent lamps are of the electronic type, and at least 50% of those sold for HID-lamps.

[100] The same conclusion was drawn in a recent CLASP report on LFL's, see section 2.4.5 in: CLASP, November 2014, "Mapping & Benchmarking of Linear Fluorescent Lighting". http://clasponline.org/en/Resources/Resources/PublicationLibrary/2014/Benchmarking-Analysis-Linear-Fluorescent-Lighting.aspx

[101] Guide of the European Lighting Industry (ELC & CELMA) for the application of the Commission Regulation (EC) No. 245/2009 amended by the Regulation No. 347/2010 setting EcoDesign requirements for "Tertiary sector lighting products", 2nd edition, September 2010, annex C5 and C6 http://www.lightingeurope.org/uploads/files/CELMA_EcoDesign_%28SM%29258_CELMA_ELC_Tertiary_Lighting_Guide_2nd_Edition_FINAL2_Sept2010.pdf

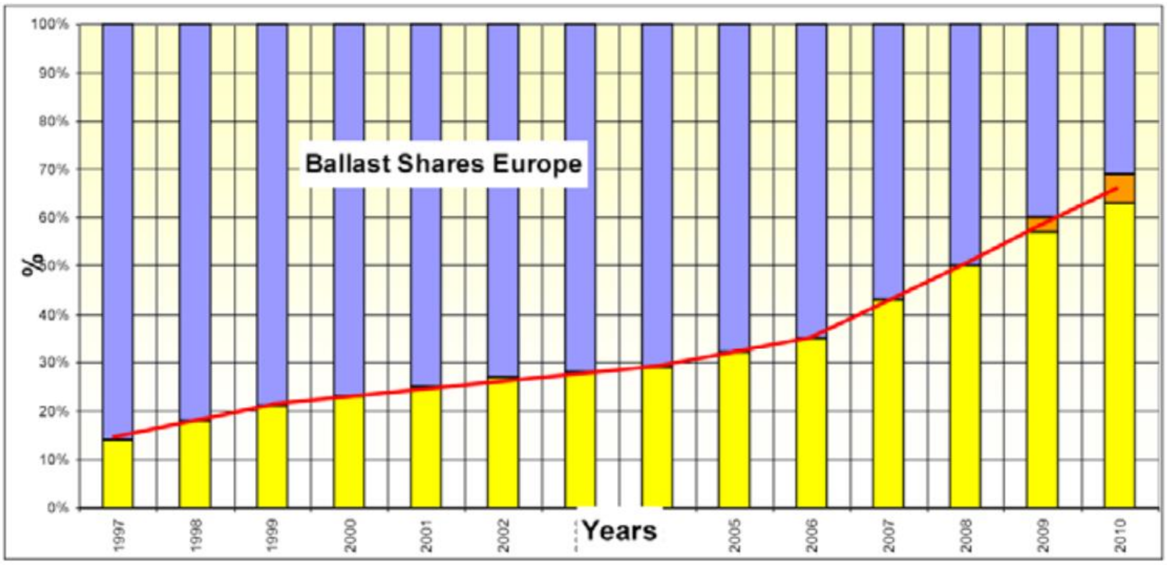


*Figure 2-1 Market share (1997-2008) and expected market share (2009-2010) of European ballast sales by type for use with linear fluorescent lamps (blue=magnetic ballast; yellow=electronic ballast; orange=tolerance band) (Source: [101])*

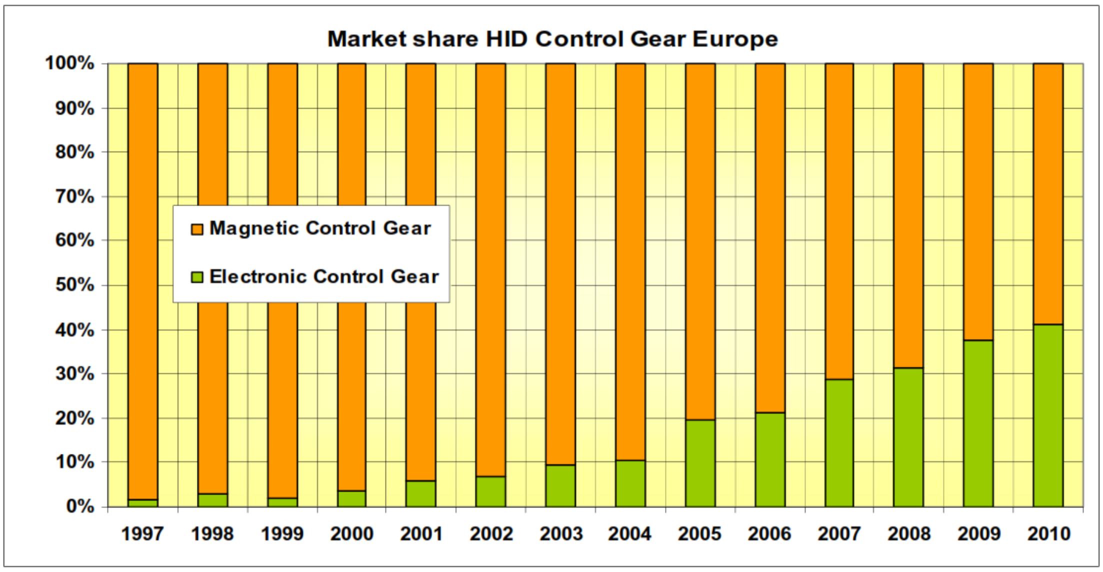


*Figure 2-2 Market share (1997-2010) of the European ballast sales by type for use with high-intensity discharge lamps (orange=magnetic ballast; green=electronic ballast) (Source: [101])*

### 2.2.4 Sales of luminaires

The following Eurostat PRODCOM codes related to luminaires could be relevant as a reference for this study:

- 27402200 - Electric table, desk, bedside or floor-standing lamps
- 27402500 - Chandeliers and other electric ceiling or wall lighting fittings (excluding those used for lighting public open spaces or thoroughfares)
- 27403930 - Electric lamps and lighting fittings, of plastic and other materials, of a kind used for filament lamps and tubular fluorescent lamps

- 27403300 - Searchlights and spotlights (including for stage sets, photographic or film studios)

The trade and sales data for the first three codes of luminaires are presented in Annex L. Luminaires for spotlights have not been reported, but sales are around 10 million units a year and thus relatively small. Considering the description of code 27402500, luminaires for lighting of roads and squares seem to be excluded from the reported data, but no separate NACE code could be found for these luminaires.

In 2013 the total number of luminaires sold (according to Eurostat, for the three codes) is around 320 million units for a total value around 9700 million euros, with an average price around 30 euros / luminaire.

In the same year the total number of light sources sold was 1700 million units, for a total acquisition value (purchase + installation) around 15 000 million euros [102], with an average value of around 9 euros / light source (incl. VAT for residential, fixed 2010 euros).

Consequently the number of luminaires sold was roughly one fifth of the number of light sources. This indicates that the average luminaire lifetime is approximately five times longer than the average light source lifetime, in the assumption of one lamp per luminaire. Taking into account more lamps per luminaire (e.g. 1,5) would indicate even lower life times. As the former is usually taken as 20 years, the latter would be around 4 years, which could be reasonable [103].

<u>It should be noted that these luminaires sales figures include for example residential luminaires and therefore are not directly applicable for the scope as defined in Task 1.</u>

### 2.2.5 Sales of sensors

The sensors of main interest for lighting systems are daylight sensors and occupancy sensors (movement-, presence-, vacancy-sensors). Looking for 'sensors' in the NACE rev. 2 classification, only one code appears (26.51.52.71) but it is related to measuring pressure and not of interest.
Other keywords have been used to search the list of NACE rev.2 codes for relevant data, but only one was found:

- 26.11.22.40 Photosensitive semiconductor devices; solar cells, photo-diodes, photo-transistors, etc.

The photo-diodes are interesting for daylight detection, but trade and sales data are combined with those for e.g. solar cells and consequently would be useless for the purposes of this study.

It is not known under which NACE code manufacturers of daylight- and occupancy sensors register their products, but it is likely that the same codes also cover other products. In addition, the same sensors can also be used for different applications to lighting systems.

Consequently: no useful trade and sales data on sensors for lighting systems is available from PRODCOM statistics.

[102] Data taken from the MELISA model.
[103] This does not take into account that several luminaires contain more than one light source …

### 2.2.6 Sales and stock of dimmers and other control devices

According to CECAPI [104], the following can be stated regarding the sales of phase-cut dimmers in Europe:

- In 2010 5.2 million phase-cut dimmers were sold in Europe 105, corresponding to 148 million euros in revenue.
- In 2013 5.8 million phase-cut dimmers are expected to be sold, corresponding to 180 million euros in revenue.
- In 2010 around 61% of the phase-cut dimmers sold were leading-edge, around 27% trailing-edge and 12% universal.
- In terms of revenues the percentages are different because leading-edge dimmers have a lower cost. In 2010 34% of the revenues from phase-cut dimmers were for leading-edge types, around 30% for trailing-edge and 36% for universal types.
- Trailing-edge dimmers are popular (accounting for 50% of unit sales or more) in the Nordic countries and in Germany.
- From 2010 to 2013 the growth will be stronger for trailing-edge dimmers than for leading-edge dimmers because the former are thought to be more suitable for CFL and LED lamps.
- In 2010 approximately 75% of the phase-cut dimmers were sold in the residential sector, and 25% in the non-residential sector, with only slight variations of this percentage per type.

In addition CECAPI estimates that the installed base of phase-cut dimmers for Europe is between 110 and 120 million units in 2010, of which 75% are installed in the residential sector. Considering that the number of households in EU-28 is around 200 million, this approximately implies that on average half or less of EU households have a phase-cut dimmer installed (half in the case of one dimmer per household).

As regards other types of dimmers and other lighting control devices, some related NACE rev. 2 product codes were identified:

- 26.11.30.03 Multi-chip integrated circuits: processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock- and timing circuits, or other circuits
- 26.11.30.06 Electronic integrated circuits (excluding multi-chip circuits): processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock- and timing circuits, or other circuits
- 26.52.28.70 Time switches with clock or watch movement or with synchronous motor (including switches for making and breaking the circuit supplying electrical apparatus)
- 27.33.11.00 Electrical apparatus for switching electrical circuits for voltages ≤ 1 kV (including push-button ad rotary switches)(excluding relays)
- CPA 27.12.24 Relays, for a voltage ≤ 1000 V
- CPA 27.33.13 Plugs, sockets and other apparatus for switching or protecting electrical circuits n.e.c.

This list is probably not complete: there is a wide variety of components that are used in lighting control and the list of potentially applicable NACE codes is long. In addition

[104] Information communicated by CECAPI to the study team on Light Sources, also reported in the Task 3 report section 7.2.8 of that study.
[105] Actually the countries covered by the study are France, Germany, Italy, UK, Denmark, Finland, Norway, Sweden, both residential and non-residential sectors.

the listed items are also used for other purposes than lighting control. Consequently it has not been deemed useful to report the corresponding trade and sales data.

It should be noted that these light control sales figures cannot directly be linked to the scope as defined in Task 1, for example those for residential application are not within the scope.
Any additional sales information on lighting controllers provided by preffesionals within the sector, is welcome..

### 2.2.7 Sales of communication devices for lighting systems

The following NACE codes have been identified as possibly covering the trade and sales data of communication devices used in lighting systems:

- 26.12.20.00 Network communications equipment (e.g. hubs, routers, gateways) for LANs and WANs and sound, video, network and similar cards for automatic data processing machines
- 26.30.23.70 Other apparatus for the transmission or reception of voice, images or other data, including apparatus for communication in a wired or wireless network (such as local or wide area network) other than transmission or reception apparatus of HS 8443, 8525, 8527 or 8528.

The same remarks apply as made for control devices above: the list is not complete and the same devices used in lighting systems can also be used for other purposes. Consequently, no sales data are reported here.

### 2.2.8 Sales and stock of wiring for lighting systems

NACE code 27.32 regards the 'Manufacture of other electronic and electric wires and cables'. However, any trade and sales data would not be specific for lighting systems.
Cable losses fom lighting circuits were already studied in the 'Preparatory Studies for Product Group in the Ecodesign Working Plan 2012-2014: Lot 8 - Power Cables'[106], this study contains more market and stock data. Cables are considered outside the scope of this study, because they were already part of another study.

### 2.2.9 Quantity, size and types of non-residential buildings and indoor spaces

#### Aim

As explained in section 2.2.1, this study will estimate the potential savings due to improved lighting systems for individual application base cases (cellular offices, open-plan offices, shops, manufacturing areas, circulation areas, etc.). For the derivation of the total EU-28 savings from these basic calculations, two approaches have been indicated:

1) Insert the base case savings in the MELISA model using the factors Fsales, Fphi and Fhour (see section 2.1.2 and 0).

2) Multiply the savings for the individual base case spaces by the number of such spaces in the EU-28 (or by a share thereof).

In the latter case it is convenient to express the base case savings per unit of area (e.g. kWh/m$^2$/a or euros/m$^2$) and to express the number of such spaces in the EU-28 as an area (m$^2$), so that the multiplication of the two provides the total EU-28 savings.

[106] http://erp4cables.net/

This sectionconcentrates on the latter approach and tries to estimate the subdivision of the total EU-28 non-residential building area over the various types of buildings/sectors and over the types of spaces/activities within these buildings.

### Sources

The reference areas for lighting in non-residential buildings have been derived starting from the report on EU-28 Building Heat Demand [107]. This report was prepared on request of the European Commission, with the aim to harmonize the basic data used in EU-studies regarding heating, cooling and ventilation of buildings. Amongst other aspects, this report provides the total EU-28 heated surface area per type of building (i.e. counting not only covered ground area, but also considering the average number of stories per building).

The report [107] is based on a variety of sources, including: GIS-based assessment of land coverage and usage (LUCAS, previously CORINE), land registry data, statistics of building permits, census data (population-wide questionnaire data conducted by EU Member States typically every ten years), monetary and real estate data, urban planning guides, analogy with the better-known residential buildings (e.g. building volume per capita), architectural guidelines, architectual data for reference buildings, economic activity (NACE) statistics, reverse engineering from energy use and sales of heating systems, information from the European Climate Change Programme, joint efforts of the national statistics offices, data from the Energy Performance of Buildings Directive, Ecodesign preparatory studies on boilers, ventilation units and air conditioners, and other sources.

Considering that the data sources for the report are considerably wider than just Eurostat statistics, that the area survey was developed specifically to harmonize the data used in EU-studies, and that the total indoor lit area would be expected to closely correspond to the heated area, the above report[107] has been used as the preferred source in this study.

The area data per type of building/sector from the Building Heat Demand report were integrated with data on the subdivision of non-residential buildings in types of rooms/spaces (offices, circulation areas, toilets, technical and service areas, etc.) provided in the same report and in other sources. In addition, data from the European Parking Association regarding parking in structures have been used [108].

With regards to the subdivision of the lit areas by type of buildings and into the types of rooms/spaces/activities within those buildings, an attempt has been made to follow (as far as available data allowed) the breakdowns used in EN-15193 and EN-12464 for the definition of default potential operating hours, absence factors, and minimum lighting requirements.

### Non-residential building area per type of building

The result of the area-analysis per type of non-residential building is shown in Table 2-4; for additional information see Annex F.

[107] "Average EU building heat load for HVAC equipment", final report, René Kemna (VHK) for the European Commission, August 2014 (chapter 4, volumes and surfaces)

[108] 'Scope of Parking in Europe – Data Collection by the European Parking Association', 2013, http://www.europeanparking.eu/cms/Media/Taskgroups/Final_Report_EPA_Data_Collectionort_final_web1%20.pdf

The total EU-28 non-residential lit building area is estimated to be 11773 $Mm^2$ (million square meters) and the largest shares are found for industry (21%), retail and wholesale (20%) and offices (18%) [109]. *This value of 11773 Mm² non-residential building area lit means about 23 m² per habitant EU28-(2015).*

The table also compares this new VHK estimate with the data previously used in Task 0 based on other study (Waide,2013)[111] based on data reported by BPIE[110] : the newer VHK estimated total EU-28 area is almost twice as large as the previous BPIE report.
Given the large discrepancy between both sources on non-residential floor area[111],[107] and the impact on the conclusion this data should be cross-checked for the final version.

*Table 2-4 Summary per building type of non-residential lighted building areas (in million square meters, M $m^2$) and comparison with data used previously in Task 0 based on Waide(2014)[111], table 1-2* ***Error! Bookmark not defined.****)*

| | EU-27 area M $m^2$ | | Share % of total | |
|---|---|---|---|---|
| | Task 0 | Current | Task 0 | Current |
| sector | | analysis | | analysis |
| | | | | |
| Education | 1001 | 1302 | 17% | 11% |
| Hotels & Restaurants | 648 | 754 | 11% | 6% |
| Hospitals (&HealthCare) | 412 | 907 | 7% | 8% |
| Retail (&Wholesale) | 883 | 2382 | 15% | 20% |
| Offices | 1354 | 2115 | 23% | 18% |
| Sports | 530 | 544 | 9% | 5% |
| Industry | 530 | 2461 | 9% | 21% |
| Other | 530 | 1308 | 9% | 11% |
| | | | | |
| **Total Non-Residential** | **5888** | **11773** | **100%** | **100%** |
| Residential (see section 2.2.10) | 17810 | 21218 | | |

### Non-residential building area per type of room/space

The result of the area-analysis per type of room/space/activity in non-residential buildings is shown in Table 2-5.
The largest area shares have been found for circulation areas (corridors, staircases, entrance halls, etc., 13.8%), manufacturing areas (12.5%), toilets showers and wardrobes (7.0%) and storerooms and warehouses (6.6%).
However, this classification is influenced by the degree of area breakdown that was possible on the basis of the available data. E.g. manufacturing areas still cover a variety of space/activity types, while offices could be split into three types (cellular offices in office buildings, open space offices in office buildings, and general small offices in non-office buildings). The three types of offices together account for 15.3% of the total building area.

[109] 11773 $Mm^2$ (million square meters) = 11773 $km^2$, corresponds to approximately 28% of the area of The Netherlands, or to 4.5 times the area of Luxembourg.
[110] http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf
[111] Paul Waide, Second edition, 13 June 2014: 'The scope for energy and CO2 savings in the EU through the use of building automation technology', http://www.leonardo-energy.org/

*Table 2-5 Summary per room type of EU-28 total non-residential lighted building areas (million $m^2$)*

| **Subdivision per type of space in Non-Residential buildings** | EU-28 area M $m^2$ | Share % of total |
|---|---|---|
| | | |
| Circulation areas | 1620 | 13.8% |
| Manufacturing area | 1476 | 12.5% |
| Toilets, showers, wardrobes | 829 | 7.0% |
| Storeroom / Warehouse | 774 | 6.6% |
| Offices (cellular) | 660 | 5.6% |
| Shops < 30 m2 | 643 | 5.5% |
| Offices (open space) | 609 | 5.2% |
| Class rooms and similar | 573 | 4.9% |
| Offices (general, small) [112] | 525 | 4.5% |
| Technical / service areas | 502 | 4.3% |
| Eating / drinking areas | 496 | 4.2% |
| Shops > 30 m2 | 402 | 3.4% |
| Meeting rooms | 362 | 3.1% |
| Theatre, Dancing, Amusement park | 358 | 3.0% |
| Parking in structures | 290 | 2.5% |
| Sports Hall | 242 | 2.1% |
| Hospital wards/bedrooms | 191 | 1.6% |
| Examination / Treatment Rooms | 180 | 1.5% |
| Waiting areas | 179 | 1.5% |
| Political and religious (incl. churches) | 152 | 1.3% |
| Video and Movie production and Cinemas | 152 | 1.3% |
| Hotel rooms (excl. toilet/shower) | 138 | 1.2% |
| Libraries, museums, zoo | 112 | 1.0% |
| Radio and TV | 107 | 0.9% |
| Laboratories | 66 | 0.6% |
| Kitchens | 60 | 0.5% |
| Waste disposal / sewage | 37 | 0.3% |
| Prisons | 34 | 0.3% |
| Fire service activities | 4 | 0.0% |
| | | |
| Total non-residential building area | 11773 | 100.0% |

## Cross check 1: required and installed lighting capacity

The areas per room/space type reported above have been verified as regards their implications for some characteristic lighting parameters.

As a first verification step, the EU-28 total areas ($m^2$) per room/space type have been multiplied by their respective minimum lighting requirements from EN 12464-1:2007 (lux = lm/$m^2$) to obtain an EU-28 total <u>required</u> lighting capacity (lm) <u>at task level</u> [113].

[112] Offices (cellular) and Offices (open space) are in office buildings. Offices (general, small) are in other building types, e.g. small administrative or management office in a supermarket, in a sports hall, or in a hospital.

[113] Including not only the task area itself, but also the surrounding and background areas, but always at 'task level', as opposed to 'light source level'.

This result is compared with the EU-28 total installed lighting capacity at light source level as computed in the MELISA model, based on sales quantities of light sources and average lighting capacities per light source type.

Details on this verification step can be found in Annex E.

The main conclusion is that the two computation methods are compatible. The total EU-28 required lighting capacity for non-residential buildings is 3648 Glm at task level. The MELISA model for 2013 gives an installed lighting capacity of 5660 Glm at light source level. This would imply an average utilization factor of 3648/5660 = 64%, a value that could be considered reasonable. It should be noted that this value might lower if the floor area is overestimated, see section 2.2.9.

Other conclusions that have been drawn from this step are:

- Office buildings account for 25% of the required lighting capacity, followed by Manufacturing/Industry (24%), Retail/Wholesale/Trade (15%) and Educational Buildings (12%). All other building types together account for 25%.

- Among room/activity types, circulation areas have the largest area share (13.8%), but they have a relatively low lighting requirement and consequently represent 'only' 6.4% of the total required lighting capacity.

- Manufacturing areas have the highest share (16.2%) of the total required lighting capacity, but this is also due to the fact that this item is not further subdivided.

- Offices have been split in cellular offices (9.0%), open space offices (9.6%), and general-small offices (7.2%) [114] that together account for 25.8% of the total required lighting capacity.

- When small shops (6.2%) and large shops (3.9%) are taken together they represent 10% of the total required lighting capacity.

- Meeting rooms (5.7%), class rooms (5.3%) and toilets/showers/wardrobes (5.3%) have comparable total required lighting capacities.

### Cross check 2: installed lighting power

As a second verification step, the installed lighting power is determined by multiplying the required lighting capacities (lm at task level from the first step) by the power density values Pjlx (W/m$^2$/lux = W/lm) suggested in prEN15193-1:2014 table C.1. These values depend on room surface dimensions and reflection factors, the height distance between luminaire and task plane, and the upward flux fractions (UFF) of the luminaires (direct or indirect lighting). The Pjlx values are valid for a maintenance factor MF=0.8 and for an overall luminaire/light source efficacy of 60 luminaire lumens per Watt.

This result is compared with the EU-28 total installed lighting power as computed in the MELISA model, based on sales quantities of light sources and average powers per light source type.

[114] The first two types are inside office buildings, the latter are offices in other buildings.

Details on this cross check can be found in Annex E.

The values calculated from EU-total areas per room type correspond surprisingly well with those computed in MELISA. In particular:

- The total EU-28 installed lighting power in non-residential buildings, considering a maintenance factor MF=0.8, and an efficacy of 60 luminaire lumens per circuit Watt, is estimated at 87 GW. For this assumption we will refer to '60 lm/W maintained luminaire efficacy'. Using the MELISA mix of lamp types for the indoor non-residential sector and the corresponding efficacy correction factors of prEN 15193, a correction factor FL=1.28 results, and the estimate for the installed power would become 87*1.28 = 111 GW. The MELISA model for 2013 gives an installed lighting power of 106 GW, which is a very close match.

- The estimated power density is 7.4 $W/m^2$ assuming 60 lm/W maintained luminaire efficacy , which should be corrected to 7.4*1.28 = 9.5 $W/m^2$ if the MELISA mix of lamp types is assumed. The MELISA value for 2013 is 9.0 $W/m^2$. All these values are relative low in comparison to the maximum illumination power per square meter that for example are used in Australian building codes (see 1.5.3.1) or in the US ASHREA 90.1 standard (see 1.4.3.4). Therefore this might imply that the current stock is already optimised in terms of installed power per m² or it might indicate that the stock area for this comparison is overestimated.

Other conclusions that have been drawn from the second verification step are:

- With respect to the building/sector types, the percentage shares of total installed lighting power are close to the percentage shares of total required lighting capacity at the task level. The reason for this is that all power density values Pjlx are estimated to be close to the average of 0.030 $W/m^2$/lux (values vary from 0.029 to 0.032, with the exception of parking areas that have 0.022). In part this small variation in Pjlx values is also caused by the application of the same efficacy of 60 luminaire lumens per circuit Watt for all building types.

- With respect to entire buildings/sectors, the installed power density is highest for office buildings (9.8 $W/m^2$ @ 60 lm/W maintained luminaire efficacy), followed by Education (8.5 $W/m^2$), Industry (8.1 $W/m^2$) and Sports (7.7 $W/m^2$). By far the lowest density is found for parking areas (1.3 $W/m^2$).

- With respect to room/activity types, the spread in Pjlx values is higher, ranging from 0.024 $W/m^2$/lux for open offices to 0.036 for small shops. The difference between open offices (0.024) and cellular offices (0.032) is noteworthy.

- With respect to room/activity types, the installed power density is highest for meeting rooms (13.8 $W/m^2$ @ 60 lm/W maintained luminaire efficacy), small offices (13.4), kitchens (13.0), cellular offices (12.9), laboratories (12.4), examination/treatment rooms (11.6) and open offices (11.1). The smallest values are estimated for parking areas (1.3 $W/m^2$ @ 60 lm/W maintained luminaire efficacy), storerooms/warehouses (2.3), churches (3.5), circulation areas (3.7) and hospital wards/bedrooms (4.4).

- The EU-28 total installed powers (@ 60 lm/W maintained luminaire efficacy) are highest for manufacturing areas (12.8 GW), cellular offices (8.5 GW), general small offices (7.0 GW), open space offices (6.8 GW), shops < 30 $m^2$ (6.4 GW), circulation areas (6.0 GW), toilets, showers and wardrobes (5.3 GW) and meeting rooms (5.0 GW). These space types together represent 66% of the total EU-28 installed power. The short list of areas could guide the choice of the base case spaces to consider for the analysis of savings due to improved lighting systems.

**Cross check 3: operating hours and energy consumption.**

As a third verification step, the lighting energy consumption is derived by multiplying the installed powers of the previous step by the annual operating hours. The multiplication itself is trivial; the problem is in establishing the operating hours for each room/space type.

The potential operating hours have been taken from prEN 15193 table B.2.3.2 (see also Annex F 2.2 of this note). Annex F 2.2 explains in detail how these I maximum annual reference operating hours from the standard have been reduced to estimated actual (full-power equivalent) hours based on the standard by means of the application of occupancy dependent factors, daylight dependent factors and constant illuminance factors. Four values for the annual operating hours are determined (and hence four values for the energy consumption), depending on the daylight availability (low or medium) and on the type of daylight dependent control (manual or best-automatic).

The same Annex F also includes comments on the potential operating hours proposed in prEN 15193. In addition the determination of a European average for the mentioned factors (even if for a specific room type) is rather complex, and the results have a large error margin. Consequently the results for the operating hours (and for the derived energy consumption) are more uncertain than those for installed capacity and power presented above.

The details of results of the analyses regarding operating hours are presented in Annex E.

The main conclusion is that the average annual operating hours as used in MELISA for the light sources of the non-residential sector are considerably lower (1467 h/a) than those derived from the potential hours in EN 15193 (2538 - 2739 h/a for manual controls and 1858 - 2120 h/a for best automated controls).
nevertheless, it is noteworthy that the values derived from EN 15193 compare well to the hours used in MELISA for linear fluorescent lamps (2200 h). A potential explanation is that MELISA also has a large quantity of incandescent, halogen and CFL light sources included in the non-residential sector, for which lower annual operating hours are assumed, and these lamps pull the power-weighted average down to 1467 h/a. Most likely incandescent, halogen and CFL lamps are used in retail, hotel and restaurants or any other areas that are outside the scope proposed in Task 1 related to EN 12464. In the total EU28 data used 41 % was allocated to the retail and industrial manufacturing sector, see 2.2.9. Also, the total area per habitant in the total non-residential sector was above 21 $m^2$ which also indicates that much of this estimated area should be unoccupied. Combining both, it could also indicate that in particular in the retail and industrial sector much of the area is storage or unrented

which could lower average annual hours. This level of detail (per lamp type) is more difficult to consider in the EN 15193 approach [115].

The difference between the two estimates confirms that lighting operating hours for the indoor non-residential sector are among the most difficult lighting parameters to establish.

Other conclusions that have been drawn from the analysis of annual operating hours are:

- With respect to building types, the highest annual operating hours are estimated for stations/airports (2849-4736 h/a), retail sector (3454-4416 h/a) and healthcare sector (2699-3854 h/a). The lowest hours have been found for Education (668-1248 h/a) and Offices (1158-1869 h/a).
- With respect to room/activity types, the highest annual operating hours are estimated for shops (3770-4610 h/a), prisons (3770-4610 h/a), laboratories (3040-4430 h/a) and hospital wards/bedrooms (3380-4220 h/a). The lowest hours have been found for technical/service areas (461-1078 h/a), class rooms (706-1359), meeting rooms (855-1499) and libraries and museums (871-1581 h/a).

The energy results are summarised in Annex F.4 and from this the following conclusions can be drawn:

- The estimate for the EU-28 annual lighting energy for non-residential buildings is between 190 and 220 TWh/a when the EN 15193 reference efficacy of 60 luminaire lumen per circuit Watt is assumed.
- Assuming the MELISA-mix of indoor non-residential lamp types and the correction factors FL suggested in EN 15193, the above energy consumption can be corrected to 240-280 TWh/a.
- The comparable MELISA value (inclusive of ballast energy) is 155 TWh/a and hence much lower than the estimate derived from the EN 15193 approach using the estimated EU-28 total room areas. This difference is almost entirely due to a difference in annual operating hours (see above).
- The overall average energy density (LENI) for EU-28 non-residential buildings is 14-20 kWh/m$^2$/a (@ 60 lm/W maintained luminaire efficacy), without correction for constant illuminance control). The corresponding 2013-value from MELISA is 13 kWh/m$^2$/a.
- As regards building types/sectors, the highest lighting energy is estimated for manufacturing/industry (38-61 TWh/a), for the retail sector (47-60 TWh/a) and for office buildings (24-39 TWh/a). The highest energy density is found for stations/airports (18-31 kWh/m$^2$/a) and for hospital/healthcare (20-28 kWh/m$^2$/a). Excluding parkings, the lowest energy density is found for educational buildings (6-11 kWh/m$^2$/a).

[115] It would require diversifying absence factors and daylight factors per lamp type rather than per room type. In other words, it should be established for each room type what part of the lamps is LFL, CFL, halogen or incandescent, and if different lamp types should have different factors.

- As regards room/activity types, the highest annual lighting energy is estimated for manufacturing areas (27.5-42.5 TWh/a), although this is exceeded if the three office types are taken together ( 31.9-49.4 TWh/a). The highest energy density is found for laboratories (38-55 kWh/m²/a), small shops (38-46 kWh/m²/a) and examination/treatment rooms (26-41 kWh/m²/a). Low density values are found for parking areas (1-3 kWh/m²/a), technical/service areas (3-6), political activities/churches (4-8) and warehouses (5-9). This could guide the choice of the base case spaces to consider for the analysis of savings due to improved lighting systems.

### 2.2.10 Quantity, size and types of residential buildings and indoor spaces

Note: This section is for information only because residential buildings are not within the scope of Task 1.

The data in Table 2-6 have also been taken from the Building Heat Demand report and show a total EU-28 residential building area of 21218 Mm². This is relatively close to the estimate of 17810 Mm² that was used in the Lot 37 exploratory study **Error! Bookmark not defined.**.

*Table 2-6 EU28-2010 RESIDENTIAL SECTOR BUILDINGS numbers and geometry*
*(Source: VHK 2014 [107])*

| RESIDENTIAL SECTOR, Category only primary dwellings taken into account | Number of blocks | Number of dwellings | **Area** | **A/unit** |
|---|---|---|---|---|
| | M units | M units | M m² | m² |
| Detached dwellings | 34 | 34 | 4385 | 128 |
| Semi-detached (2 dwellings/block) | 20 | 39 | 4700 | 128 |
| Terraced houses (block of 15 dwellings) | 2.3 | 35 | 3824 | 128 |
| **Single family/duplex dwellings** | **56** | **108** | **12909** | |
| City blocks (130 apartments) | | | | |
| Low-rise detached apartment blocks (25 app.) | 12.8 | 102 | 8310 | 81 |
| High-rise apartment blocks (130 apartments) | | | | |
| **Multi-family dwellings** | **13** | **102** | **8310** | |
| **TOTAL RESIDENTIAL SECTOR** | **68** | **210** | **21218** | **0** |

As regards the breakdown of this area by room type, the Building Heat Demand report provides 2013 data for a reference dwelling in Germany [116] [117] (Table 2-7):

*Table 2-7 Breakdown of floor area for a reference dwelling in Germany 2013*
*(Extract from [116])*

116 Forschungsstelle für Energiewirtschaft (FfE), Bewertung und Vergleich flächenspezifischer Größen – Auf die Definition kommt es an, BWK Bd. 65 (2013) Nr. 5.

117 As also shown in Table 11 of the Building Heat Demand report, the (heated and lighted) residential building area depends on the source. There are differences depending on definition between e.g. floor area, habitable surface, useful area, net floor area, etc.. For example DIN 277 does not consider the 13 m² for hall way as useful area (but it is lighted); also terraces are not always counted (but often lighted).

| All surfaces in m² | Floor area |
|---|---|
| Living room | 33 |
| Kitchen | 14 |
| Bathroom | 10 |
| Hallway | 13 |
| Toilet | 5 |
| Bedroom | 17 |
| (Terrace) | (8) |
| Total reference floor area | 92 (100) |

Other reference area data for lighting in residential buildings can be found in e.g. EN 15193 ( see Table 2-8).

*Table 2-8 Reference useful areas for the lighting of rooms in residential buildings (Source: table B.3.3.8 of prEN 15193-1:2014(E))*

| | | Area (m²) | | |
|---|---|---|---|---|
| | | Small | Medium | Large |
| Kitchen | General and ambient lighting | 6 - 8 | 8 - 10 | 10 - 12 |
| | Worktop lighting | 2 | 2 | 2 |
| Dining room | General and ambient lighting | 8 - 12 | 12 - 16 | 16 - 20 |
| | Dining table lighting | 3 | 3 | 3 |
| Living room | General and ambient lighting | 8 - 12 | 12 - 16 | 16 - 20 |
| | Reading lights | 1 | 1 | 1 |
| Bathroom and toilets | General and ambient lighting | 4 - 6 | 6 - 8 | 8 - 10 |
| | Mirror lighting | 1 | 1 | 1 |
| Bedroom | General and ambient lighting | 6 - 8 | 8 - 12 | 12 - 16 |
| | Bedside lamps | 1 | 1 | 1 |
| | Desk lamps | 1 | 1 | 1 |
| Entrance hall, corridors and stairs | General and ambient lighting | 1 - 3 | 3 - 5 | 5 - 7 |
| Storeroom, cellar and laundry room | General and ambient lighting | 4 - 6 | 6 - 8 | 8 - 10 |

### 2.2.11 Quantity, length and types of roads

Eurostat provides road transport infrastructure statistics [118], that contain the following road categories:

- Motorways, which belong typically to EN 13201-2 oe CIE 115 road class M (see Task 3 for typical road infrastructure geometry and surface). Total length reported is 63.660 km in EU28 (2010), with large networks in Spain, France and Germany.
- E-roads: which also belong typically to EN 13201-2 oe CIE 115 road class M (see Task 3 for typical road infrastructure geometry and surface). Total length reported is 42.409 km in the EU28 (2010).
- State, province and communal roads, which belong typically to EN 13201-2 oe CIE 115 road class C (see Task 3 for typical road infrastructure geometry and surface). Total length reported is 3.616.472 km in the EU28 (2010).

[118] http://ec.europa.eu/eurostat/web/transport/data/database

- Other roads inside or outside built up areas: which also belong typically to EN 13201-2 oe CIE 115 road class P (see Task 3 for typical road infrastructure geometry and surface). Total length reported is identical to -state, province and communal roads.

This data is incomplete, because years and counties are missing, and therefore derived and processed data sources will be used. Also there is no clear distinction in data between -state, province and communal roads and other roads inside or outside built-up areas.

Another source for information on the lengths of different road types in the different EU-28 Member States is “European Road Statistics” of the European Road Federation for 2011[119].

This data does not include statistics on lit roads, therefore further processing is necessary.

[119] ERF, European Road Statistics 2011, http://www.irfnet.eu/index.php/publications/publications/european-road-statistics-handbook

*Tabel 2-1 Length of total road network by category in km in 2008 (Source: European Road Statistics 2011[120])*

| Type | Motorways | Main or national roads | Secondary or regional | Other roads | Total |
|---|---|---|---|---|---|
| **EN 13201 Typical class** | M | M | C | P | |
| **country** | | | | | |
| Total EU | 69559 | 272044 | 1516784 | 2289378 | |
| BE | 1763 | 12613 | 1349 | 13787 | 153595 |
| BG | 418 | 2975 | 16042 | n.a. | n.a. |
| CZ | 691 | 621 | 48753 | 74919 | 130573 |
| DK | 1128 | 2711 | 69492 | 73331 | |
| DE | 12645 | 40203 | 178151 | 413.289 | 644288 |
| EE | 104 | 3889 | 12494 | 41547 | 58034 |
| IE | 423 | 501 | 11645 | 79447 | 96525 |
| EL | 1103 | 10189 | 30864 | 756 | 117756 |
| ES | 13515 | 11875 | 139621 | 501053 | 666064 |
| FR | 11042 | 9765 | 377984 | 629 | 1027791 |
| IT | 6629 | 1929 | 157785 | 312.100 | 495804 |
| CY | 257 | 2131 | 2745 | 3585 | 8718 |
| LV | 1649 | 18529 | 49508 | 69686 | |
| LT | 309 | 6385 | 14625 | 5971 | 81029 |
| LU | 147 | 837 | 1891 | 2875 | |
| HU | 1274 | 6973 | 23927 | 16617 | 198344 |
| MT | 184 | 665 | 1379 | 2228 | |
| NL | 2637 | 2413 | 7848 | 123237 | 136135 |
| AT | 1696 | 10442 | 23673 | 74394 | 110205 |
| PL | 765 | 17754 | 28474 | 21424 | 261233 |
| PT | 2623 | 5958 | 4409 | 639 | 79513 |
| RO | 281 | 16318 | 65094 | 81693 | |
| SI | 696 | 935 | 5085 | 32219 | 38935 |
| SK | 384 | 3443 | 14089 | 25942 | 43858 |
| FI | 739 | 12593 | 13493 | 51317 | 78142 |
| SE | 1855 | 13474 | 83138 | 11713 | 215597 |
| UK | 3559 | 48957 | 122322 | 244645 | 419483 |
| HR | 1043 | 6966 | 10904 | 10335 | 29248 |

### 2.2.12 Generic economic and MELISA model data conclusion

The Eurostat production and trade statistics (PRODCOM) do not provide data on sales of Lighting Systems as a whole. Sales data have been found for some of the

[120] http://www.irfnet.eu/index.php/publications/publications/european-road-statistics-handbook

components of lighting systems, in particular for light sources, ballasts / control gears, luminaires and phase-cut dimmers. For other control devices, sensors, communication devices and wiring, no specific sales information related to their use in lighting systems has been found.
Although sales data for Lighting Systems are difficult to determine, there is no doubt that the eligibility criterion of Art. 15-2a of Directive 2009/125/EC is met, because the quantity of new lighting installations is well above 200 000 units per year.

Two methods have been identified to compute the savings due to improved lighting systems. The first method uses MELISA and the system influence factors Fsales, Fphi and Fhour discussed in sections 2.1.2 and 0. The second method consists in multiplying the computed savings per unit of building area or road length for the base case spaces (indoor or outdoor; kWh/m$^2$/a, euros/m$^2$/a, kWh/km/a, euros/km/a) by the quantity of such spaces in the EU-28 (in m$^2$ or km). For this reason the report provides the EU-28 total areas of non-residential buildings, subdivided per building type and per room type, the total areas of residential buildings, and the EU-28 total lengths of roads.

In a cross-check, the reported areas for rooms/spaces in non-residential buildings were used in combination with information, methods and requirements from the standards EN 12464-1 and EN 15193 to compute the EU-28 total lighting requirement (expressed in terms of lumens at the task level), the EU-28 total installed lighting power, and the EU-28 total lighting energy consumption. Lighting capacity and power were found to be in good agreement with the values from the MELISA model that were computed in a completely different manner, based on light source sales quantities and average light source characteristics (lumen, power, efficacy).

For lighting energy, the estimate using building areas leads to a higher indoor non-residential lighting energy (240-280 TWh/a) than the MELISA model (155 TWh/a). There are many factors both in this estimate based on EN 15193 and the MELISA model that can explain such differences. EN 15193 uses default operating hours per type task area which are corrected downwards based on occupancy and daylight data and their types of associated control system. These occupancy and daylight correction factors as defined in EN 15193 will be further discussed and analysed in more detail in Task 3 on Users. The real data related to occupancy and daylight in the existing stock are however often unknown. As explained before (see 2.2.9), this deviation from the standard operating hours might be allocated to particular area's such as storage area's used in retail and industry with low operating hours. Therefore one explanation might be lower operating hours in MELISA compared to the EN 15193 estimate. In section 2.2.9 it was also suggested that the main deviation might come from operating hours for incandescent, halogen and CFLi lamps used in the non-residential sector. It is unlikey that these lamps are used for area's defined in the scope of this study that is limited to area's for indoor work places where standard EN 12464 can be applied. Such area's that are therefore excluded from the scope could be found in within hotels, restaurants and shops that use ambient lighting not following EN 12464. Despite all this, many other factors than annual operating hours could explain such differences, such as in EU 28 estimated annual energy consumption. For example, in MELISA the lamp life times ( 13000 h for LFL T8t, 12000h for HPS, 8000h for HPM) and/or the average lamp wattages (30 W for LFL T8t, 121 W for HPS, 208 W for HPM) could be in the real stock higher as assumed resulting in an underestimated energy consumption. Finally there are also uncertainties on the total estimated building stock area and their relative shares of different types of task areas (office, corridor, storage, etc.). This MELISA cross-check analysis used a total of 11,77 Bn m² non-residential building area lit (source: VHK (2014)[121]). It is above 23 m² lit non-residential indoor area per habitant in the EU28 (2015), which is relatively high and therefore occupancy could be low and/or the stock area could be overestimated. For comparison Task 0 used only 5,800 Bn m² non-residential building area based on BPIE market data[72],[110]. A smaller non-residential area would result in a higher LENI estimate, e.g. 13x11.8/5.8 = 26 kWh/(m².y) which is more in line with LENI data used in field applications such as illustrated in section 1.5.2.4. More accurate building stock data from stakeholders is welcome.

Given these considerations and for the purpose of this study we think that both modelling approaches are valid and useful for this study. More precise metrics of the lighting stock do not currently seem to be available; however, we believe that the uncertainties are not so significant as to merit discontinuation of the study nor to unduly delay any implementing measures in the context of Ecodesign Regulation[122]. In Task 7 a sensitivity analysis could allow a better understanding of the importance of these differences and result in a closer estimate for impact accounting of policy measures. In further tasks calculations will be done based on EN 15193 reference values, with a sensitivity analysis for lower annual operating hours in Task 7.

According to our analysis, the **types of indoor non-residential spaces with the highest energy impact** in EU-28 are: **offices, manufacturing areas, shops (retail), circulation areas and toilets/showers/wardrobes**. Together these spaces consume almost 70% of the total EU-28 indoor non-residential lighting energy. Base case analyses will concentrate on these space types.

### 2.2.13 Additional market and stock data for indoor lighting

#### *2.2.13.1 2007 installed base lighting control (lot 8)*

The following data can be reused from the preparatory study on office lighting lot 8[98]:
Generally a lighting control (mechanism) can be classified in switch or modulation control, manual or automatic control, and central or local control. Although almost every combination is possible, the most frequently used systems are: automatic local switching on by presence or occupancy detection, automatic time switch, automatic local daylight compensation and of course the classic manual switches which can be local or central.

[121] Average EU building heat load for HVAC equipment", final report, René Kemna (VHK) for the European Commission, August 2014 (chapter 4, volumes and surfaces)

[122] Article 15 (a) in the Ecodesign Directive 2009/125/EC says 'consider the life cycle of the product and all its significant environmental aspects, inter alia, energy efficiency. The depth of analysis of the environmental aspects and of the feasibility of their improvement shall be proportionate to their significance. The adoption of ecodesign requirements on the significant environmental aspects of a product shall not be unduly delayed by uncertainties regarding the other aspects'

| Type of control system used | Data | Ref year | Source | Region |
|---|---|---|---|---|
| Manual control | 97% | 2000 | DEFU, 2001 in IEA, 2006 | Europe-6[123] |
| Switching on/off per lamp | 3-4% | | Kantoor 2000 | Belgium |
| Switching on/off per room | 68% | | Kantoor 2000 | Belgium |
| Switching on/off centrally | 19% | | Kantoor 2000 | Belgium |
| (Timed) lighting sweep function or switch[124] | 12% | 2002 | SenterNovem[125] | Netherlands |
| | 11% | 2003 | | |
| scheduling (timer switchers) | 4% | 2000 | DEFU, 2001 in IEA, 2006 | Europe-6 |
| some kind of automatic control (occupancy sensors, daylight dimming, etc.). | 3% | 2000 | DEFU, 2001 in IEA, 2006 | Europe-6 |
| Daylight compensation | 0,7% | | Kantoor 2000 | Belgium |
| Daylight depending lighting | 19% | 2002 | SenterNovem[126] | Netherlands |
| | 22% | 2003 | | |
| Switching on/off by presence detection | 8% | | Kantoor 2000 | Belgium |
| Occupancy detection | 10% | 2002 | SenterNovem | Netherlands |
| | 12% | 2003 | | |

*Table 2-9 Penetration rate of different lighting control techniques in office lighting*

| | In small offices (<30 m²) | | In larger offices (>30 m² or more than 6 persons) | |
|---|---|---|---|---|
| | Belgium | Spain | Belgium | Spain |
| Daylight sensors | 10% | 5% | 15% | 10% |
| Individual control for each user | 1% | 20% | 5% | 20% |
| Presence detection | 25% | 10% | 25% | 15% |

*Table 2-10 Penetration rate of different lighting control techniques in office lighting in Belgium and Spain (Source: Expert inquiry)*

The German respondent (2007) remarked that these control techniques are heavily promoted but find little acceptance. Next to the common reason that the investment is usually not paid for by the end user, another reason is low customer satisfaction, anger about malfunctioning sophisticated electronic control gear. Adding to this, what is never mentioned in the promotion is that optimised lamps and luminaires already reduce the energy demand of a lighting system to a rather low level and that in turn the automatic control gear also requires some power (usually for 8760h/a), which at least partly offsets the energy savings achieved during office hours.

In Belgium daylight compensation was only found in buildings where special attention was already given to energy efficiency/savings at the design stage. Only relatively few offices are equipped with dimming that allows continuous supplement of the variable contribution of daylight to the desired lighting level. In the Netherlands SenterNovem found in 2003[125] that this technique is already much more applied.

[123] Results from a survey in six EU countries; No full survey exists for Europe as a whole
[124] (Timed) lighting sweep function or switch. With a sweep function at a certain moment (for example at the start of a break) the full lighting is switched off. Users have to switch on the lighting again themselves.
[125] SenterNovem (2003) Monitor Energiebesparende maatregelen. Rapportage EBM
[126] SenterNovem (2003) Monitor Energiebesparende maatregelen. Rapportage EBM

The SAVE report "Market research on the use of energy efficient lighting in the commercial sector" (DEFU, 2001) concluded that controls in public office buildings in 6 European countries (F, B, DK, ES, GR, IT, UK) were overwhelmingly manual. Over 90% of rooms had manual controls in all countries except UK. In the UK 85% of rooms had manual control only, 12% had occupancy sensing, the remainder had a mixture of controls including time scheduling. There is a need to establish lighting control in the market place. The only considerable share of automatic control installed was in UK with 12-28% in offices (DEFU, 2001).

Note: the previous data sources are old (1999-2007) and it is likely that the current situation changed to higher degrees of automation. Any new source on information on the current status is welcome.

### 2.2.13.2 Cellular versus open plan offices

Source lot 8 (2007):
No data on the ratio of cellular versus open plan offices could be found for the EU25, or at Member State level. Only The Kantoor 2000-study for Belgium reports that 48% of total offices are open plan offices and 52% cellular offices.
The share of open plan versus cellular offices strongly varies between buildings and is closely connected to the company philosophy and activity. On average over the full building sample, the share of both types of offices are almost equal.

### 2.2.13.3 Direct lighting versus indirect lighting luminaires in offices

Source lot 8 (2007):
In this section we focus on the shares of A1[127] versus A2[128] type office luminaires (see chapter 1) in the installed base. Data on this issue could be retrieved from the DEFU study (DEFU, 2001) and the expert inquiry.

The weighted average derived from the DEFU figures gives a distribution of 73% A1 luminaires versus 27% A2 luminaires installed in European offices.

This seems to be well in line with the results retrieved from the expert inquiry. The expert inquiry shows that while in existing lighting installations only 10-15% (Belgium and Germany versus Spain) of the installed base are suspended luminaries (A2 luminaires), in new installations 20% (Belgium), 30% (Spain) to 50% (Germany) are suspended luminaries with direct/indirect light.

[127] Only direct light, often ceiling mounted
[128] Direct/indirect light, often suspended

| % | | Total number (n) | Direct | Semi-direct | Indirect | Total |
|---|---|---|---|---|---|---|
| | | | A1 | A2 | | A2 |
| **Belgium** | public | 259 | 98,1 | 0,7 | 1,2 | 1,9 |
| **Denmark** | public | 486 | 64 | 35 | 1 | 36 |
| | private | 197 | 78 | 19 | 3 | 22 |
| **Spain** | public | 142 | 97,9 | 2,1 | 0 | 2,1 |
| | private | 116 | 94,8 | 2,6 | 2,6 | 5,2 |
| **Greece** | public | 337 | 45,4 | 38,6 | 16,0 | 54,6 |
| | private | 232 | 68,5 | 27,6 | 3,9 | 31,5 |
| **Italy** | public | 257 | 92,6 | 1,2 | 6,2 | 7,4 |
| | private | 344 | 44,5 | 52,6 | 2,9 | 55,5 |
| **UK** | public / private | 258 | 99 | 0 | 1 | 1 |
| **Total (Weighted average)** | | 2628 | 1926 (73%) | | | 701 (27%) |

*Table 2-11 Use of lighting technology in percentage for the public and private office buildings (Source: DEFU, 2001)*

## 2.2.14Additional market and stock data for road lighting

### *2.2.14.1 Other market data sources from road lighting*

An overview of consulted literature in the search of street lighting market data is included in the reference list. Lighting Europe has published several documents in their work on the revision of the European ecolabel and Green Public Procurement criteria for light sources (see http://www.eco-lighting-project.eu/).
In the ecodesign street lighting study (lot 9, VITO, 2007), scattered data on the number of lighting points, road width, distance between lighting poles and energy consumption of street lighting were retrieved from the literature review for several Member States. These data were complemented with the results of an "Expert inquiry".

Work Package 2 'Market assessment and review of energy savings' of the E-street Initiative published data from specific countries that indicate a relation between the number of inhabitants and number of light points for street and road lighting. For example data came from Germany where the total number of outdoor light points is known (approximately 9 million street light luminaires installed for 82 million inhabitants). An extrapolation for Europe was made based on **this ratio of 0,12 luminaires/capita**..

*Table 2-12 Market data on installed base of street lighting luminaires in EU-25 (Source : data from literature and expert inquiry completed with CELMA market data estimations for missing Member States) (Source: lot 9, VITO, 2007)*

| 2005 | Luminaires TOTAL | %EU25 | Capita ('000) | Luminaires/capita | Source |
|---|---|---|---|---|---|
| Austria | 1.000.000 | 1,8% | 8.207 | 0,12 | CELMA |
| Belgium | 2.005.000 | 3,6% | 10.446 | 0,19 | Filled out inquiry with lamp data from SYNERGRID (2005) |

| 2005 | Luminaires TOTAL | %EU25 | Capita ('000) | Luminaires/capita | Source |
|---|---|---|---|---|---|
| Czech republic | 300.000 | 0,5% | 10.221 | 0,03 | CELMA |
| Denmark | 780.000 | 1,4% | 5.411 | 0,14 | Mr. Thomas Christoffersen, based on data for city of Copenhagen |
| Finland | 400.000 | 0,7% | 5.237 | 0,08 | CELMA |
| France | 8.570.000 | 15,3% | 60.561 | 0,14 | ADEME (2006) and %HgHP adapted based on feedback Mr. Fourtune (email, 3/10/2006) |
| Germany | 9.120.000 | 16,3% | 82.501 | 0,11 | Philips AEG Licht GmbH/WestLB AG/ WestKC GmbH (2003) |
| Greece | 900.000 | 1,6% | 11.076 | 0,08 | CELMA and email Mr. Paissidis (15/06/2006): most commonly used lamp types: 400W NaHP for cat. F roads, HgHP 125, 80W for cat. M roads, HgHP 125W and (but minority) 100, 150W NaHP for cat. S roads. Some roads are over lit (e.g. cat. F roads about 6 cd/m2) other roads are not or poorly lit (even in cat. S). |
| Hungary | 600.000 | 1,1% | 10.098 | 0,06 | CELMA |
| Italy | 9.000.000 | 16,0% | 58.462 | 0,15 | ASSIL |
| Netherlands | 2.500.000 | 4,5% | 16.306 | 0,15 | Projectbureau energiebesparing Grond-, Weg- en Waterbouw (GWW) (2005); ECN (2000) Partly filled out inquiry by B. Hamel, RWS |
| Poland | 4.200.000 | 7,5% | 38.174 | 0,11 | Email Mr. R.Zwierchanowski and Mr. J. Grzonkovski. |
| Portugal | 1.100.000 | 2,0% | 10.529 | 0,10 | CELMA |
| Sweden | 2.500.000 | 4,5% | 9.011 | 0,28 | Filled out inquiry Mr. Frantzell |
| Spain | 4.200.000 | 7,5% | 43.038 | 0,10 | IDAE (2005) |
| Slovakia | 200.000 | 0,4% | 5.385 | 0,04 | CELMA |
| UK | 7.851.000 | 14,0% | 60.035 | 0,13 | Filled out inquiry and extra data Ms. Hillary Graves |
| Latvia | 85.000 | 0,2% | 2.306 | 0,04 | CELMA |
| Lithuania | 125.000 | 0,2% | 3.425 | 0,04 | CELMA |
| Estonia | 50.000 | 0,1% | 1.347 | 0,04 | CELMA |
| Malta | 45.000 | 0,1% | 403 | 0,11 | CELMA |
| Cyprus | 88.000 | 0,2% | 775 | 0,11 | CELMA |
| Luxembourg | 61.000 | 0,1% | 455 | 0,13 | CELMA |
| Ireland | 401.000 | 0,7% | 4.109 | 0,09 | Filled out inquiry, Mr. M. Perse (ESB) |
| Slovenia | 74.000 | 0,1% | 1.998 | 0,04 | CELMA |
| **Total EU25** | **56.155.000** | **100%** | **459.514** | 0,12 | |

**A European average of 0,12 Light Points per Inhabitant (LPI)** will be used in this study.

#### 2.2.14.2 Share of lit roads

The lot 9 preparatory study on street lighting estimated the share of lit roads as follows:

- 10% of category fast traffic roads (lot 9) in 1990 or typically road class M (motorized) in EN 13201 and motorways.
- 15% of mixed traffic roads (lot 9) in 1990 or typically road class C (conflict) in EN 13201 and intercommunal roads.
- 30% of slow traffic roads(lot 9) in 1990 or typically road class P (pedestrian) in EN 13201 and roads in residential areas.

In the eco-design street lighting study (VITO, 2007) it was assumed that 10% of category F roads, 15% of category M roads and 30% of category S roads were lit in 1990, increasing linearly to 15% Cat F, 17,5% Cat M and 40% Cat S roads lit in 2025. The main driving forces for this growth in road lighting are a.o.: increases in road infrastructure, increased passenger and freight transport activity, the high cost of accidents, and the ageing of the overall population with diminished visual capacities.

#### 2.2.14.3 Cross check with MELISA on light sources sales for road lighting

This is work in progress.

#### 2.2.14.4 Conclusion on Market and stock data in road lighting

Because the past and future sales and stock data for road lighting luminaires or lighting points sales is not directly available a forecast was made based on the previous data. The data sources used are the average road length data (section 2.2.11), typical light pole distances (section 3.1.2), share of lit roads per category (section 2.2.14.2), average luminaire life time (section 3.4.1.2) and installed lighting points per inhabitant (section 2.2.14.1). The combination of this data results in an installed stock and annual sales forecasts included in Table 2-13, the estimate for installed stock of road lighting luminaires was about 68 million light points with an annual sales of 2.29 million luminaires for replacements and 0.82 million for new roads. This data will be used further in the study.

*Table 2-13 EU28 annual road lighting luminaire stock and sales estimate*

| **Road Type** | Motorways | Main or national roads | Secondary or regional roads | Other roads | Total |
|---|---|---|---|---|---|
| **EN 13201 Typical lighting class** | M Motorized traffic | M Motorized traffic | C Conflict traffic | P Pedestrian traffic | |
| **road lenght statistics Member State** | **length (km)** | **length (km)** | **length (km)** | **length (km)** | **length (km)** |
| Total EU28 | 68251 | 281095 | 1410180 | 3543979 | 5303505 |
| **Technical parameters market** | | | | | |
| average pole distance(m) | 45 | 45 | 30 | 25 | |
| share lit (%) corrected | 14% | 14% | 20% | 41% | |
| corrected poles (base LPI) 2010 | 207057 | 852773 | 9625809 | 58058401 | 68744039 |
| **Sales and stock street lighting luminaires** | | | | | |
| Average economic life time | 30.00 | 30.00 | 30.00 | 30.00 | |
| Annual luminaire sales for replacement 2010 | 6902 | 28426 | 320860 | 1935280 | 2291468 |
| Annual luminaire sales stock growth | 1,2% | 1,2% | 1,2% | 1,2% | |
| Annual luminaire sales for new road 2010 | 2485 | 10233 | 115510 | 696701 | 824928 |
| Stock forecast 2020 | 233289 | 960812 | 10845320 | 65413923 | 77453344 |
| Annual luminaire sales for replacement 2020 | 7776 | 32027 | 361511 | 2180464 | 2581778 |
| Annual luminaire sales for new road 2020 | 2799 | 11530 | 130144 | 784967 | 929440 |
| Stock forecast 2020 | 262845 | 1082539 | 12219333 | 73701329 | 87266046 |
| Annual luminaire sales for replacement 2020 | 8761 | 36085 | 407311 | 2456711 | 2908868 |
| Annual luminaire sales for new road 2020 | 3154 | 12990 | 146632 | 884416 | 1047193 |

## 2.3 Market trends

### 2.3.1 Market production structures

#### *2.3.1.1 Luminaires and other components for lighting systems*

Please consult the Light Source study.

#### *2.3.1.2 Green public procurement*

The Green Public Procurement's legislative document is the communication on ''Public procurement for a better environment'' COM (2008) 400[129] **accompanied by the European GPP training toolkit.** The stated GPP target in the renewed Sustainable Development Strategy was that by the year 2010, the average level of GPP should have been the same as the 2006 level of the best performing Member States.

The approach under GPP is to propose two types of criteria for each sector covered:

[129] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0400:FIN:EN:PDF

- The **core criteria**, which are those suitable for use by any contracting authority across the Member States and address the key environmental impacts. They are designed to be used with minimum additional verification effort or cost increases.
- The **comprehensive criteria**, which are for those who wish to purchase the best environmental friendly products available on the market. These may require additional verification effort or a slight increase in cost compared to other products with the same functionality.

Just as the Ecolabel is a voluntary scheme, which means that producers, importers and retailers can choose to apply for the label for their products; GPP is also a voluntary instrument, which means that Member States and public authorities can determine the extent to which they implement it.

In June 2010, a **new procedure for EU GPP criteria development** was put in place in order to make the criteria development process more participatory and enhance synergies among different product-related policy instruments, for example EU GPP and EU Ecolabel[130]. The Procedure for the development and revision of EU GPP criteria is explained on the GPP website[131].

For several product groups common GPP criteria[132] are already developed in the framework of the training toolkit on GPP or are in the process of being developed (cfr work plan for 2015-2016)[133].
At present the following lighting equipment is covered:

- Indoor Lighting[134]
  Covering "*lamps, luminaires (light fittings) and lighting controls installed inside buildings*" with stated exceptions for specialist lighting.

- Street Lighting and Traffic Signals[135]
  Covering "*Fixed lighting installation intended to provide good visibility to users of outdoor public traffic areas during the hours of darkness to support traffic safety, traffic flow and public security*".

The relevant key environmental impacts identified in the GPP criteria for indoor lighting are:

- energy consumption
- polluting processes during manufacture
- hazardous constituents
- waste generation

The relevant key environmental impacts identified in the GPP criteria for street lighting and traffic signals are:
- energy consumption
- use of natural resources
- hazardous constituents
- waste generation

130 http://ec.europa.eu/environment/gpp/gpp_criteria_process.htm
131 http://ec.europa.eu/environment/gpp/gpp_criteria_procedure.htm
132 http://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm
133 http://ec.europa.eu/environment/gpp/gpp_criteria_wp.htm
134 http://ec.europa.eu/environment/gpp/pdf/criteria/indoor_lighting.pdf
135 http://ec.europa.eu/environment/gpp/pdf/criteria/street_lighting.pdf

- light pollution

Note: Currently (2016) the GPP criteria for street lighting and traffic signs are reviewed, more information can be found on this website: http://susproc.jrc.ec.europa.eu/Street_lighting_and_Traffic_signs/

##### *2.3.1.2.1 Implementation status of GPP criteria*

In the 2008 Communication "Public Procurement for a Better Environment", the European Commission set an indicative target that, by 2010, 50% of all public tendering procedures should be green in the EU, where "green" means compliant with endorsed common core EU GPP criteria for ten priority product/service groups such as construction, transport, cleaning products and services.
In 2011, the Commission commissioned a study with the aim of **measuring if this target had been met**. Since there are **no systematic statistics on GPP in the Member States**, the Centre for European Policy Studies and the College of Europe conducted a survey in which over 850 public authorities from 26 Member States participated. The respondents provided detailed answers regarding the use of core GPP criteria in the last contract they had signed for one of the ten product/service groups and gave more general information on the "greenness" of their overall procurement in the period 2009/2010. For this general part, the study collected information on more than 230,000 contracts signed by public authorities in 2009-2010, for a value of approx. 117.5 billion Euros.

The main findings of the report are:

- Although the uptake of Green Procurement in the EU is significant, **it appears that the 50% target has not been met**. 26% of the last contracts signed in the 2009-2010 period by public authorities in the EU included all surveyed EU core GPP criteria. However, 55% of these contracts included at least one EU core GPP criterion, showing that some form of green procurement is being done at a large scale. The study also points towards **an overall positive trend in the period 2009-2010**.
- Another positive result is that the greenness of contracts seems to be higher when looking at the value of contracts compared to the number of contracts. 38% of the total value of the contracts included green criteria.
- In line with earlier research, the study highlights that **the uptake of EU GPP criteria varies significantly across Europe**. Looking at the last contract signed by public authorities, there are four top performing countries (Belgium, Denmark, Netherlands and Sweden), in which all EU core GPP criteria were applied in 40%-60% of the cases. On the other hand, there are as many as twelve countries where this occurred in less than 20% of the last contracts. There are some variations in the results when looking at the uptake of at least one criterion and for all contracts of the period 2009-2010. For some countries, the results have to be read with caution, due to a low participation in the survey.
- Moreover, the study shows that **purchasing costs are still the predominant criterion for awarding contracts**. 64% of the respondents mainly used the lowest price as the decisive criterion, while only a minority predominantly use Life Cycle Costing evaluation methods.

Since "Street lighting and traffic signals" and "Indoor lighting" GPP criteria are quite recent, it is difficult to estimate the value of the contracts including green criteria for these product groups. An assessment of the trend will be further analysed during Task 2 of the Eco-lighting project.

An overview of GPP good practice cases are listed on the Commission's website[136] both for indoor lighting as for street lighting and traffic signals.

##### 2.3.1.2.2 Impacts of GPP on lighting systems

New EU Green Public Procurement (GPP) criteria for indoor lighting were introduced in 2012[137]. They relate not only to minimum luminous efficacy of the light sources (in lm/W), but also to lighting levels (W/m²/100 lux), lighting controls, etc. (VHK, 2013)
A revision of GPP criteria for street lighting is planned in 2016-2017.

#### 2.3.1.3 Concept of Total cost of ownership (TCO) or Life cycle cost(LCC) used in lighting systems

LCC is being applied by many public authorities across the EU and in a range of sectors.
Under the EU procurement rules a contract can be awarded based on lowest price or Most Economically Advantageous Tender (MEAT). Where the second option is chosen, costs may be calculated on the basis of the whole life-cycle of the supplies, services or works, and not solely on the purchase price. This allows costs associated with the use, maintenance and end-of-life of the supplies, services or works to be taken into account – sometimes also referred to as the Total Cost of Ownership.

In the example the higher initial purchase price of the green product is more then compensated by the much smaller use/operating and EOL costs (Figure 2-3). For a large number of products the operating costs constitute a significant share of the cost a procurement agency will have to pay for. This is typically the case for energy-using products such as vehicles, IT equipment or lighting, and buildings (for which the operational costs can run up to 85% of the total life cycle costs) (EC, 2008).



[136] http://ec.europa.eu/environment/gpp/case_group_en.htm
[137] http://ec.europa.eu/environment/gpp/pdf/criteria/indoor_lighting.pdf

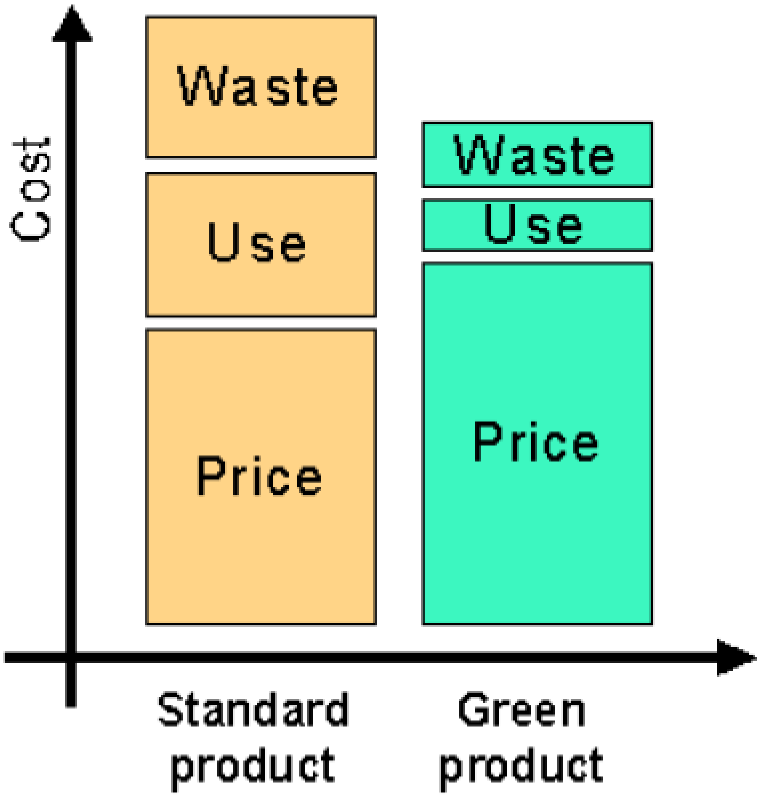


*Figure 2-3: Influence of use and End of Life costs on the total costs (Source: EC, GPP training toolkit, module 1 'managing GPP implementation – LCC factsheet', 2008)*

Life-cycle costing or LCC is a tool which evaluates the costs of an asset throughout its life-cycle.
The conventional LCC techniques most widely used by companies and/or governments is based on a purely financial valuation. Four main cost categories are assessed: investment, operation, maintenance and end-of-life disposal expenses.

An environmental LCC methodology takes into account the above four main cost categories **plus external environmental costs**. The latter may come from LCA analyses on environmental impacts, which measure for example the external costs of global warming contribution associated with emissions of different greenhouse gases. Environmental costs can be calculated also in respect of acidification (grams of $SO_2$, $NO_X$ and $NH_3$), eutrophication (grams of $NO_X$ and $NH_3$), land use ($m^2$*year) or other measurable impacts.

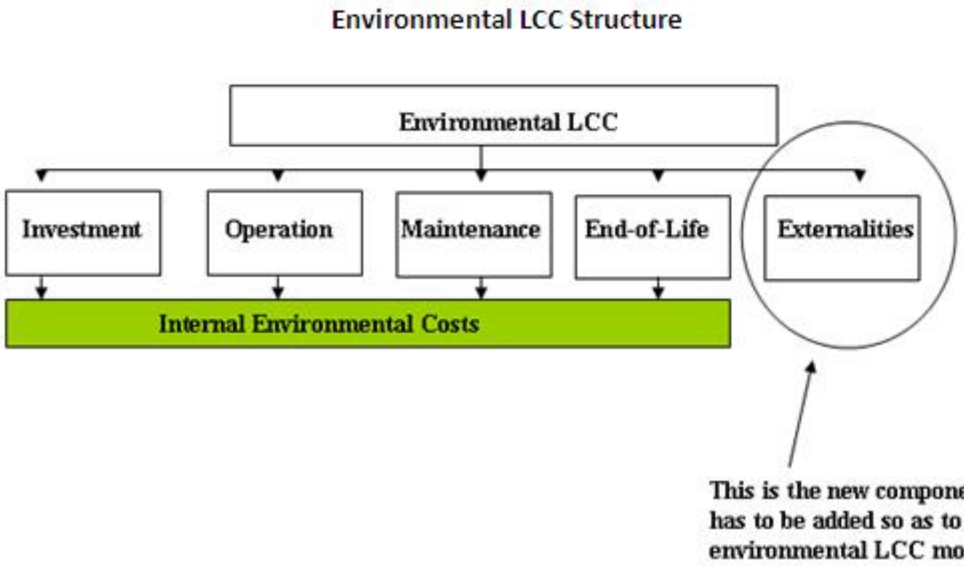


*Figure 2-4: Environmental LCC structure (Source: European Commission Life cycle costing web page[138], consulted on 25 November 2015)*

To be introduced into an 'accounting' LCC process, environmental costs must be expressed in monetary terms. In other words, environmental costs should be quantified and monetised so they can be considered as an additional cost input in a LCC analysis.
An environmental LCC is not a stand-alone technique but draws upon the results from appropriate environmental Life-cycle Assessment (LCA) analyses.

**Further information on LCC in procurement**

- The *Buying Green!* A handbook on green public procurement (Second edition 2011) contains a section on LCC
- The following publication also gives a useful background on environmental LCC: Hunkeler, D., Lichtenvort, K. and Rebitzer, G. (eds) *Environmental Life-cycle Costing* CRC Press, 2008
- Further information on LCC in procurement is available from the Procura+ manual[139]

**LCC Tools**

The Swedish Environmental Management Council (SEMCO) has developed several excel tools for calculating life-cycle costs in public procurement. In addition to a general tool, specialised ones are available for professional kitchens (fridges and freezers), indoor and outdoor lighting and vending machines. More information is available on the website[140].

The **SMART-SPP project**[141] developed and tested a tool for public authorities to assess LCC and $CO_2$ emissions and to compare bids for products using electricity. It[142] is available to download in four languages.

[138] http://ec.europa.eu/environment/gpp/lcc.htm
[139] http://www.procuraplus.org/
[140] http://www.msr.se/en/green_procurement/LCC/
[141] http://www.smart-spp.eu
[142] http://www.smart-spp.eu/guidance

The **European Commission is developing a calculation tool on life-cycle costing** with the aim to facilitate the use of the LCC approach amongst public procurers. The LCC calculation tool will be elaborated in accordance with art.68 of the new Public Procurement Directive 2014/24/EU and it will be focusing on specific product categories such as Office IT Equipment, **Lighting (Indoor Lighting)**, White Goods, Vending Machines and Medical Electrical Equipment.
The project has started in January 2015 and results are expected for the second part of 2016. The Commission organized a webinar in which the concept of the calculation tool was presented, see agenda[143].

In the white paper 'Life cycle costing. A question of value' of IISD (2009) a selection of LCC tools and guidelines is listed.

### 2.3.2 General trends in product design and product features; feedback from consumer associations

Lighting system design and installation services is a mature business, and lighting designers are organized into various organisations. To support their activities lighting design standards and software tools have been developed, see Task 1 for a listing.

## 2.4 Consumer expenditure data

### 2.4.1 Design, installation and repair cost

It is common practice that lighting design is included in the price quoted for the luminaires and it is proposed to apply this practice in this study.
Luminaire prices for typical installation designs are included in Task 4.
Typical installation and repair times are discussed in Task 3 and costs can be calculated based on hourly rates.

The average hourly rates in the EU28 are shown in Table 2-14 and are used as the installer's hourly rate or for repairs and maintenance such as lamp replacement or cleaning.

[143] http://ec.europa.eu/environment/gpp/pdf/Webinar_LCC_June2015.pdf

*Table 2-14 hourly rates in EU-28[144]*

| | 2008 | 2010 | 2011 | 2012 | 2013 | Non-wage costs (% of total), 2013 | Change 2013/2008, % |
|---|---|---|---|---|---|---|---|
| EA17 | 25.7 | 26.9 | 27.5 | 28 | 28.4 | 25.90% | 10.40% |
| EA18 | 25.5 | 26.7 | 27.3 | 27.8 | 28.2 | 25.90% | 10.40% |
| EU28 | 21.5 | 22.4 | 22.9 | 23.4 | 23.7 | 23.70% | 10.20% |
| Belgium | 32.9 | 35.3 | 36.3 | 37.2 | 38 | 27.40% | 15.40% |
| Bulgaria | 2.6 | 3.1 | 3.3 | 3.6 | 3.7 | 15.80% | 44.10% |
| Czech Republic | 9.2 | 9.8 | 10.5 | 10.5 | 10.3 | 26.80% | 12.40% |
| Denmark | 34.4 | 36.7 | 37.3 | 38 | 38.4 | 12.40% | 11.70% |
| Germany | 27.9 | 28.8 | 29.6 | 30.5 | 31.3 | 21.80% | 12.20% |
| Estonia | 7.8 | 7.6 | 7.9 | 8.4 | 9 | 26.70% | 15.20% |
| Ireland | 28.9 | 28.9 | 28.7 | 29 | 29 | 13.80% | 0.50% |
| Greece | 16.7 | 17 | 16.2 | 15 | 13.6 | 19.10% | -18.60% |
| Spain | 19.4 | 20.7 | 21.2 | 21 | 21.1 | 26.60% | 8.70% |
| France | 31.2 | 32.6 | 33.6 | 34.3 | 34.3 | 32.40% | 9.90% |
| Croatia | 9.2 | 8.6 | 8.7 | 8.7 | 8.8 | 15.40% | -4.00% |
| Italy | 25.2 | 26.8 | 27.2 | 27.6 | 28.1 | 28.10% | 11.40% |
| Cyprus | 16.7 | 17.7 | 18 | 18 | 17.2 | 16.60% | 2.60% |
| Latvia | 5.9 | 5.5 | 5.7 | 6 | 6.3 | 20.60% | 7.10% |
| Lithuania | 5.9 | 5.4 | 5.5 | 5.8 | 6.2 | 28.50% | 5.00% |
| Luxembourg | 31 | 32.9 | 33.9 | 34.7 | 35.7 | 13.40% | 15.40% |
| Hungary | 7.8 | 7 | 7.3 | 7.5 | 7.4 | 24.60% | -5.20% |
| Malta | 11.3 | 11.9 | 12.2 | 12.5 | 12.8 | 8.00% | 13.90% |
| Netherlands | 29.8 | 31.1 | 31.6 | 32.3 | 33.2 | 24.70% | 11.70% |
| Austria | 26.4 | 28 | 29 | 30.5 | 31.4 | 26.70% | 18.90% |
| Poland | 7.6 | 7.2 | 7.3 | 7.4 | 7.6 | 16.70% | 0.10% |
| Portugal | 12.2 | 12.6 | 12.6 | 11.6 | 11.6 | 19.30% | -5.10% |
| Romania | 4.2 | 4.1 | 4.2 | 4.1 | 4.6 | 23.20% | 10.60% |
| Slovenia | 13.9 | 14.6 | 14.9 | 14.9 | 14.6 | 14.70% | 4.90% |
| Slovakia | 7.3 | 7.7 | 8 | 8.3 | 8.5 | 27.40% | 17.00% |
| Finland | 27.1 | 28.8 | 29.5 | 30.8 | 31.4 | 22.10% | 15.90% |
| Sweden | 31.6 | 33.6 | 36.4 | 39.2 | 40.1 | 33.30% | 26.90% |
| United Kingdom | 20.9 | 20 | 20.1 | 21.6 | 20.9 | 15.30% | -0.30% |
| Norway | 37.8 | 41.6 | 44.5 | 48.5 | 48.5 | 18.90% | 28.20% |

[144] Labour costs in the EU28, Eurostat news release 49/2014, 27 March 2014

### 2.4.2 Disposal and dismantling cost

Lighting Systems are not disposed of as a whole but is related to disposal of the components. Therefore it is assumed that this is covered by the MELISA model from the Light Sources study.
To consider: extra material for luminaires? Light poles?

### 2.4.3 Electricity prices

Electricity prices are already defined in MELISA, but some background information is presented below. Table 2-15 shows the average tariffs and financial rates in the EU27 suggested in the MEErP 2011 Methodology. These rates will be used in this preparatory study according the MEErP methodology.

| | Unit | domestic incl.VAT | Long term growth per yr | non-domestic excl. VAT |
|---|---|---|---|---|
| **Electricity (base 2011)** | € / kWh | 0.18 | 5% | 0.11 |
| **Discount rate for energy**<br>**(In lot 7 and MELISA also called 'Energy escalation rate ')*** | % | | 4% | |
| **= real (inflation-corrected) increase* | | | | |

*Table 2-15 Generic energy rates in EU-27 (1.1.2011)*

### 2.4.4 Financial rates

Electricity prices are already defined in MELISA, but some background information on financial values to be applied in the study is presented below.

Table 2-16 shows the average financial rates in the EU27 suggested in the MEErP 2011 Methodology. These data can be used for Life Cycle Cost calculations in Tasks 5 to 7.

| | | |
|---|---|---|
| **Discount rate (EU default)**<br>**= interest – inflation** | % | 4% |
| **VAT** | % | Not applied for non-residential applications |

*Table 2-16 Generic financial rates in EU-27*

## 2.5 Recommendations

### 2.5.1 Refined product scope

A more refined market analysis was done on which typical task areas and/or building applications consume significant amounts of lighting energy. This showed that apart

from office spaces, circulation area's, manufacturing area's, toilet rooms, storeroom/warehouses and shops are also significant.
This study builds on the previous office lighting and road lighting study but when defining reference applications in Task 4 it could be worth considering other applications that have significant impact of this study.

### 2.5.2 Barriers and opportunities from the economical/commercial perspective

Lighting system design and maintenance will be discussed in Task 3 but the added complexity can provide an incentive or added value for energy service companies (ESCO's)[145] when they combine technical knowledgde with financial capacities. The ESCO business model could become a one-stop shop including lighting systems that enable builders, developers, owners, operators and occupants of buildings to purchase energy efficient light. An ESCO might be well placed to offer a single-point access to a full range of services from product sourcing to design, financing and installation.

Any other suggestions from stakeholders is welcome.



[145] Role of ESCO's see: IAE Energy Efficiency Market Report 2014 (EEMR 2015), www.iea.org

# CHAPTER 3 Users

**The Objective**

The objective of this task is to identify the system aspects of the use phase, especially user requirements. Relevant user-parameters are an important input for the assessment of the environmental impact of a product during its use and end-of-life phase, in particular if they are different from the standard measurement conditions as described in subtask 1.2.

**Summary of task 3:**

This is a draft version made in a preparatory phase of the study in order to collect data from stakeholders. A summary of this task will be elaborated during the completion of the draft final report.

This section identifies and provides important data for modelling the impact of the use phase of lighting systems within the scope of this study. In order to collect and discuss real user data, the development and selection of some reference lighting applications is necessary. As the purpose of this study is to build on the past eco-design preparatory studies: lot 8 on office lighting and lot 9 on street lighting, the reference applications used in those studies are reused here and aligned with the new EN standards and definitions set out in Task 1. The proposed reference lighting applications to be considered in more detail are:

- Cellular office with ceiling mounted luminaires (cellular ceiling mounted)
- Cellular office with suspended luminaires (cellular suspended)
- Open plan office with ceiling mounted luminaires (open ceiling mounted)
- Open plan office with suspended luminaires (open suspended)
- Motorized road with fast traffic class M3 (EN 13201)
- Conflict road with mixed traffic class C3 (EN 13201)
- Pedestrian area road with slow traffic class P3 (EN 13201)

To model the impact of the use-phase energy calculations are proposed in line with standards EN 15193 for indoor lighting and prEN 13201-5, see Task 1. In this Task some reference design data is included for the selected applications and potential deviations under real circumstances are discussed.

Dialux files modelling the reference designs are available on request for those stakeholders who want to contribute in Task 4.

Comment: This report is currently a work in progress, as some parts of the study have not yet received the benefit of comments and data from stakeholders, therefore it should not be viewed as a draft final report.



## 3.1 How to define MEErP system aspects of lighting systems

### 3.1.1 MEErP system aspects of lighting systems and lighting products

The Directive 2009/125/EC establishes a framework for the setting of Ecodesign requirements for energy-'related' products (ErP) and is a recast of Directive 2005/32/EC on Ecodesign requirements for energy-'using' products (EuP). For this purpose the MEErP method introduced[146] the concepts of: ErP with direct impact, ErP with indirect impact and ErP with direct + indirect impact, as illustrated in Figure 3-1. The MEErP proposed that in principle, three large groups of products can be distinguished:

[146] http://www.meerp.eu/

- products that are using energy during the use phase (hereafter 'direct ErP'),
- products that - in the use phase - do not use energy but have a significant impact on the energy consumption of products that are using energy (hereafter 'indirect ErP').
- the combination of both

In the MEErP[147] it is proposed to follow a technical systems approach taking into account 'MEErP System Aspects', i.e. considering that the ErP is part of a larger product system and –through certain features of the ErP— can influence the functional performance and/or the use of resources and emissions of the larger product system. However, the MEErP did not include a strict, nor a clear, definition of what is a product or a system. Because this study is concerned with 'lighting systems' the MEErP proposed approach might be confusing and therefore the following approach is suggested for use in this study:

- The lighting system 'product' defined in Task 1 in this study is a system or installation that is composed of luminaires, lamps,sensors and controls to satisfy lighting requirements according to EN 12464 or EN 13201. A lighting system in this study forms part of the building or road infrastructure.
- In this study the 'MEErP system aspects' of a lighting system are the building or road infrastructure such as walls, ceiling, road surface, ducts, lighting poles or supports, connectors, power cables, etc.

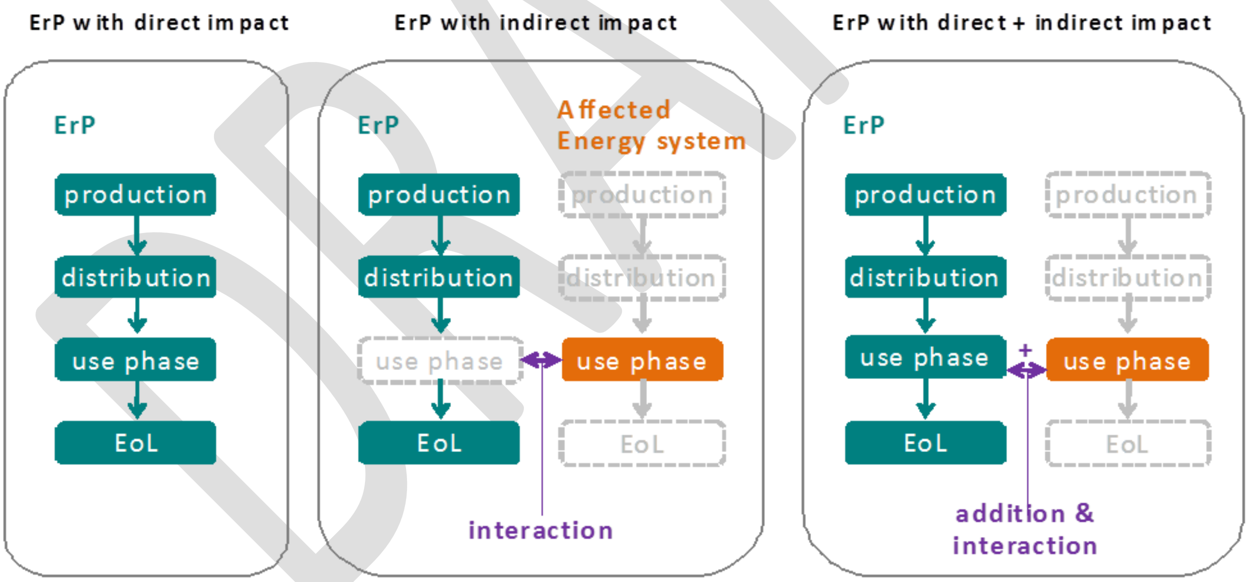


*Figure 3-1: Three groups of ErP, distinguished by their impact (source: MEErP 2011 Methodology Part 1).*

The question if 'installed lighting systems in buildings or in road lighting are products in the meaning of the Ecodesign of Energy Related Products Directive (2009/125/EC)?' is discussed in section 1.3.1. In the approach of this study following the MEErP they are considered as products[148]).

[147] http://www.meerp.eu/
[148] http://ecodesign-lightsources.eu/

Following the previous definition of 'lighting system' and 'MEErP system aspects and looking at the three broad MEErP product groupings defined in Figure 3-1 road lighting belongs to the category 'ErP with direct impact' and indoor lighting to the category 'ErP with direct + indirect impact'. This is because indoor lighting can replace the heat demand on buildings and/or contribute to the cooling load, therefore this will be studied in a separate section. For outdoor lighting there is no such indirect energy impact identified.

### 3.1.2 Reference lighting system designs and lighting schemes for use in this study

**Objective:** In order to collect and discuss real data the development of some reference lighting applications is necessary. As the purpose of this study is to build on the past eco-design preparatory studies: lot 8 on office lighting and lot 9 on street lighting, the reference applications used in those studies are reused here and aligned with the new EN standards and definitions set out in Task 1. These reference applications together with some selected lighting designs or schemes are also candidates to become so-called MEErP Base Cases in the later Tasks 5 to 7. If considered necessary, depending on the outcomes of later Tasks 2 and 4 new reference applications can be added in a later version of this report, for example if some innovations or impact cannot be covered with the current selection. Stakeholders are also invited to present additional sources of data.

#### 3.1.2.1 Cellular office with ceiling mounted luminaires

*Figure 3-2: Cellular office with ceiling mounted luminaires reference design*

A model office was defined (Figure 3-2) with the following design parameters:

Office task area lighting requirements are established according to EN 12464 (see Task 1):

Em (minimum maintained average illuminance): 500 lx
UGR (glare): ≤ 19
U0 (uniformity): ≥ 0.6
Ra (CRI): ≥ 80

Task area: whole floor area in the reference design (optimisation will be done in Task 4).

Primary functional unit (see definition in Task 1): 500 lx per hour

Occupants:

Two, each with an office desk (see Figure 3-2).

Funiture:

Reference simulation will be done without furniture.

Office geometry and properties:

Room length: 3.6 m (one side with window)
Room depth: 5.4 m
Height of window: 2.8 m
Height Task area: 0.8 m
distance from luminaire to-work plane:  2 m
Space Height Ration (SHR): 1
Reflectance ceiling: 0.7 (which is a default values in EN 15193)
Reflectance Walls: 0.5 (which is a default values in EN 15193)
Reflectance floor cavity: 0.2 (which is a default values in EN 15193)
Suspension ratio: 0 (which means the luminaire is ceiling mounted)
Window orientation: South oriented To Be Confirmed(TBC) (= default value in Dialux 4)
Latitude/Longitude (location): 50°/-9° (Frankfurt, DE)

Office geometry and properties:

Room length:  3.6 m (one side with window)
Room depth: 5.4 m
Height of window: 2.8 m

### 3.1.2.2 Cellular office with suspended luminaires

*Figure 3-3: Cellular office with suspended luminaires reference design*

A similar model office to section 3.1.2.1 was defined with suspended luminaires (Figure 3-3) and with the following design parameters:

Office task area lighting requirements according to EN 12464 (see Task 1):

Em (minimum maintained average illuminance): 500 lx
UGR (glare): ≤ 19
U0 (uniformity): ≥ 0.6
Ra (CRI): ≥ 80

Task area: whole floor area in the reference design (optimisation will be done in Task 4)

Primary functional unit (see definition in Task 1): 500 lx per hour

All parameters are identical compared to previous section 3.1.2.3 apart from the Suspension Ratio (=0.25), which means the luminaire is ceiling mounted.

### *3.1.2.3 Open plan office with ceiling mounted luminaires*

*Figure 3-4: Open plan office with ceiling mounted luminaires reference design*

A model office was defined (Figure 3-4) with the following design parameters:

Office task area lighting requirements according to EN 12464 (see Task 1):

- Em (minimum maintained average illuminance): 500 lx
- UGR (glare): ≤ 19
- U0 (uniformity): ≥ 0.6
- Ra (CRI): ≥ 80
- Task area: whole floor area in the reference design (optimisation will be done in Task 4)

Primary functional unit (see definition in Task 1): 500 lx per hour

Occupants:

Up to twentyfour, each having an office desk (0.7 x 1.8 m) (see Figure 3-4).

Office geometry and properties:

- Room length: 16.2 m (one side with window)
- Room depth: 10.8 m
- Height of window: 2.8 m
- Height Task area : 0.8 m
- Distance from luminaire to-work plane: 2 m
- Space height Ratio (SHR): 1

Reflectance ceiling: 0.7 (which is a default values in EN 15193)
Reflectance Walls: 0.5 (which is a default values in EN 15193)
Reflectance floor cavity: 0.2 (which is a default values in EN 15193)
Suspension ratio: 0 (means ceiling mounted)
Window orientation: South oriented TBC
Latitude/Longitude (location): 50°/-9° (Frankfurt, D)

### 3.1.2.4 Open plan office with suspended luminaires

A model office was defined (Figure 3-4) with the following design parameters:

Office task area lighting requirements according to EN 12464 (see Task 1):
Em (minimum maintained average illuminance): 500 lx
UGR (glare): ≤ 19
U0 (uniformity): ≥ 0.6
Ra (CRI): ≥ 80
Task area: whole floor area in the reference design (optimisation will be done in Task 4)
Primary functional unit (see definition in Task 1): 500 lx per hour

All parameters are identical compared to previous section 3.1.2.3 apart from the Suspension Ratio (=0.25), which means the luminaire is ceiling mounted.

### 3.1.2.5 Motorized road traffic class M3

A model street was defined for modelling of a motorway with fast motorized traffic use only; which corresponds to the road class M3 (Motorized) in EN 13201 (Figure 3-5).

Road class M3 (ME3b) requirements according to EN 13201-2 (see Task 1):
Lm: 1.0 Cd/m²
U0 dry conditions (uniformity): ≥ 0.4
TI (glare): 15 %
EIR (Edge Illumination Ratio on edge 3.5 m width) (edge illumination ratio): 0.5 (should this be applied to the emergency lane?)
Requirements on the emergency lane (TBD)
With regards to the emergency lane and EIR the proposal is:
C4 class lighting on the emergency lane (3 metre width)
Because there are C4 class requirements on the emergency lane no EIR (=0) requirements are needed.
The benefit of this approach is that UF data of the lot 9 study can be used.
Note: we are aware that different approaches are used in Member States but think this is a reasonable working compromise for this study.

Primary functional unit (see definition in Task 1): 1.0 Cd/m² per hour

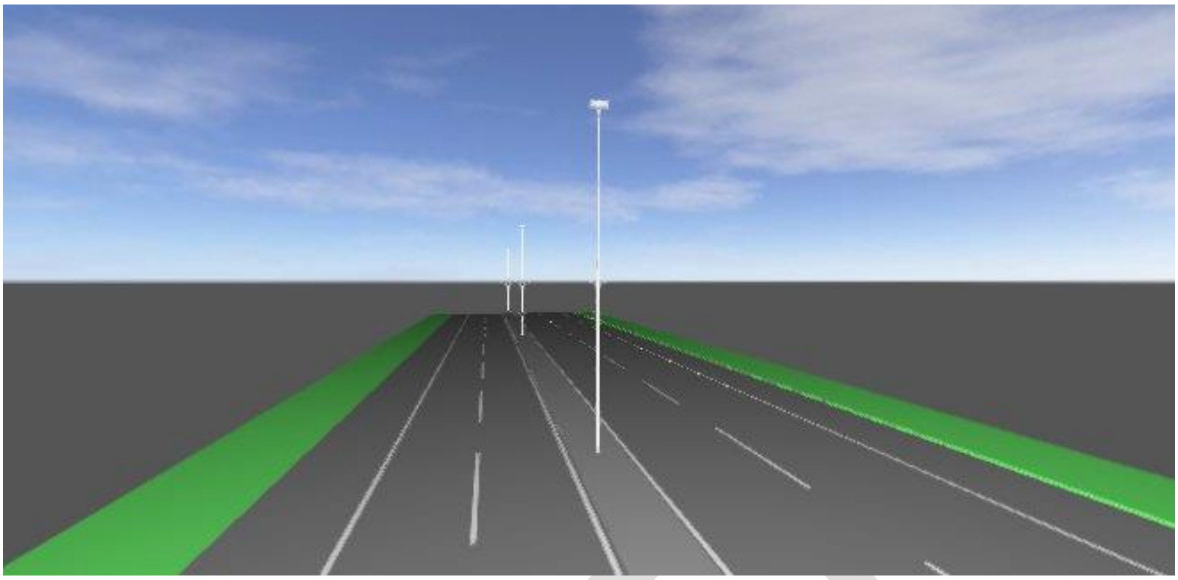

*Figure 3-5: Reference design for road class M3*

Road geometry and properties:

Light point distance/light pole height (m): 45/15 (Space Height Ratio typically around 4 and pole distance between 35 up to 80 m)
Road width (m) (half of 2x2) (incl. emergency lane): 2x10 m
hard shoulder/emergency lane: 2x3 m
centre beam: 2 m
Qo luminance coeff. Road: 0.07
Qo luminance coeff. Surround: 0.1

#### 3.1.2.6 Conflict road traffic class C3

A model street was defined for a mixed traffic road with motorized traffic, slow moving vehicles, and possibly cyclists and pedestrians; which is similar to class C3 (Conflict) in EN 13201.

Road class C3 requirements according to EN 13201 (see Task 1):

Em: 15 lx
U0 dry conditions (uniformity): ≥ 0.4
TI (glare): 20 %

Primary functional unit (see definition in Task 1): 15 lx per hour

Road geometry and properties:

Light point distance/light pole height (m): 30/8 (Space Height Ratio typically between 3 and 4.54 and pole distance between 25 up to 50 m)
Road width (m) (half of 2x2) (incl. pedestrian lane): 10 m
Pedestrian lane: 2x1.5 m
Qo luminance coeff. Road: 0.07
Qo luminance coeff. Surround: 0.1

Note: The public surrounding space next to the traffic lanes can differ strongly in residential areas depending on whether there are: separate parking lanes or not, separate footpaths or not, green strips between traffic lanes and footpaths or not, etc. Many commercial areas only allow traffic during the night and the early morning. As a consequence they do not have separate traffic lanes and footpaths, which is assumed in this reference application.

#### *3.1.2.7 Pedestrian road traffic class P3*

A model street was defined for mainly urban and pedestrian areas corresponding to road class P3 (Pedestrian) in EN 13201.

Road class P3 requirements according to EN 13201 (see Task 1):
Em: 7.5 lx
Emin: 1.5 lx
Primary functional unit (see definition in Task 1): 7.5 lx per hour

Road geometry and properties:
Light point distance/light pole height (m): 25/5 (Space Height Ratio typically between 4 and 5 and pole distance 15 up to 50 m)
Road width (m): 8 m

## 3.2 Direct impact of the lighting system on the use phase

**Scope:** The objective of this section is to identify, retrieve and analyse data and report on the environmental & resources impacts during the use phase for ErP with a *direct* energy consumption effect. Indoor lighting and road lighting are discussed in separate sections and align with the descriptions, scope and terminology used in EN standards as much as possible.

### 3.2.1 Energy consumption of indoor lighting systems in the use phase according to EN 15193

#### *3.2.1.1 Energy of indoor lighting systems according to EN 15193*

These formulas were introduced in Task 1 in Figure 1-3 and the relevant part is included in Figure 3-6. The most important parameter is the Lighting Energy Numerical Indicator (LENI, EN 15193) which represents the annual energy consumption(kWh) per square meter.

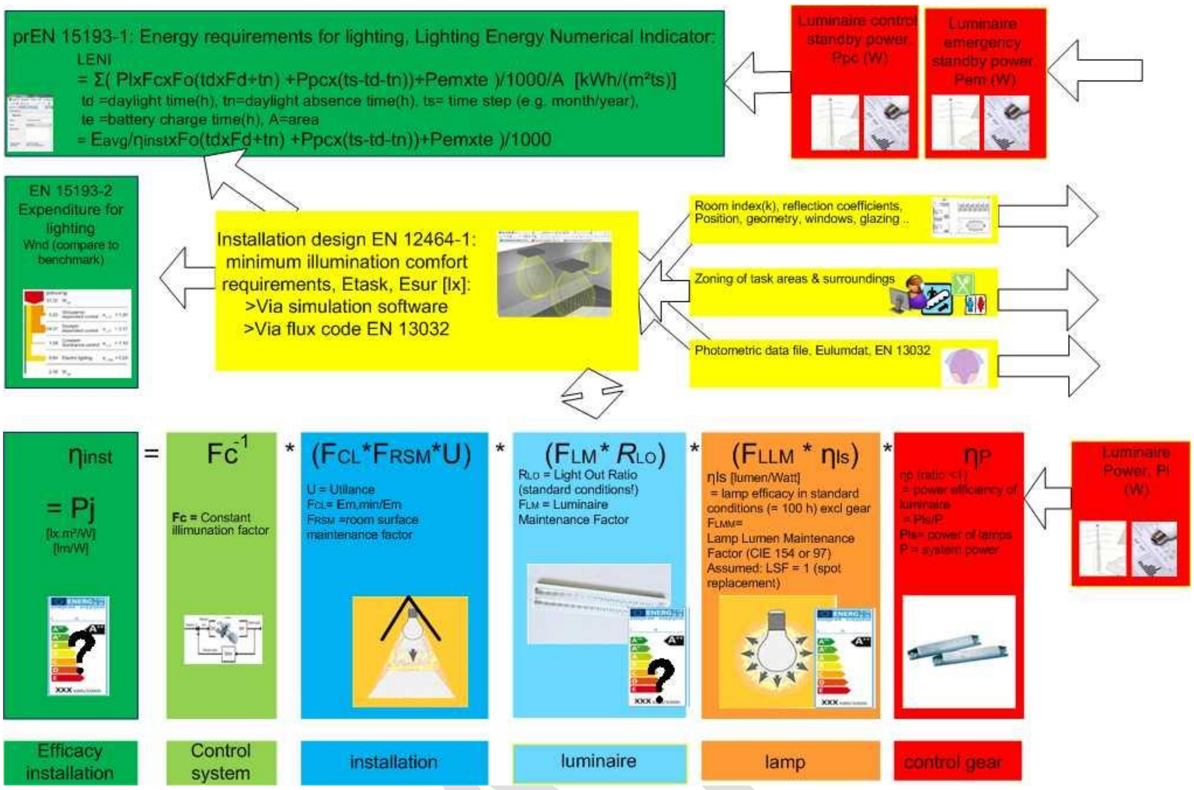


*Figure 3-6 Formulas for modelling energy consumption in indoor lighting*

### 3.2.1.2 Use parameters influencing lighting system control

#### 3.2.1.2.1 Day time, night time and occupied period

Daylight and occupancy control can deliver significant energy savings. In order to help assess how much EN 15193 is used the standard defines the following periods:

- **ty =** Annual operating hours (ty) – defined as 8 760 hours
- **td =** day light (h/ty), default values per type of building are defined in annex B
- **tn =** night time (h/ty), default values per type of building are defined in annex B
- **to =** occupied period (h/ty), = td+tn

**Values used for this study:**
Annex B of EN 15193 defines the values of td = 2250 h/y and tn = 250 h/y for office buildings. It should be noted that these are default values that are corrected downwards for occupancy and daylight with factors Fo and Fc according to the formulas in Figure 3-6 as will be explained in later sections.

#### 3.2.1.2.2 Occupancy Dependency Factor (Fo)

*An **Occupancy Dependency Factor** (**Fo**) is defined in EN 15193 to model the impact of occupancy control.*

**Approach:**
This is a correction factor applied to the operational hours that is calculated from an absence factor (Fa), as defined for different types of reference rooms (cellular office, open plan office, etc..), and an occupancy control factor (Foc), as defined for different types of control (centralised control, presence detector, etc.).

**Background:**
The user influence on final lighting energy consumption is to a large extent driven by how the light installation reacts on the presence or absence of the user. Several switching schemes are possible which allow the installation to reduce the lighting intensity or even to switch the installation off completely when the user is absent. The extent to which the user is absent is therefore the first important factor used to define the effect of different switching schemes on the final energy consumption.

Different light switching schemes interact directly or indirectly with users according to their presence. In reality, the number of potential switching schemes available is very large. In every type refinements are possible and often combinations of different types are required to obtain a suitable solution for a specific building. These refinements have an influence on the energy efficiency of the installation. However, it is necessary to apply generalisations for this study, and the available switching schemes have therefore been grouped into the following predominant types.

- “Centralised control”: all lighting in the building is centrally switched on and off. This scheme permits hardly any interference with presence of the building users.
- “Manual control”: this scheme allows the users to switch on the light at arrival and to switch it off on departure. Acceptable occupancy interference and energy saving is possible as long as the areas controlled by the switches remain small enough. EN-15193-1 makes a distinction above and below 30m² controlled area per switch. This is applied for all areas except meeting rooms.
- “Manual control and automatic sweep”: The automatic sweep (switched off timer) adds additional programming of automatic sweeps, and centrally switches off all lights in the evening, with the exception of some lights which remain active during the night.
- “Presence detection”: Similarly to manual control, the effectiveness of presence detection is largely influenced by the area which it controls. A mark of 30 m² per controlled area is again defined to distinguish 'small' and 'larger' office areas.
- “Manual control + presence detection to switch off”: in this scheme presence detection is only used to switch off the lights 5 minutes after the last presence was detected.

Most commercially available switching schemes can be categorised into one of the described types. The following table gives absence factors for these different schemes for the specific office areas. The factor Foc is the occupancy dependency factor which relates the installed power to the occupancy period.

*Table 3-1: Typical occupancy dependency factors (Foc) (source: EN15193-1)*

| **Systems without automatic presence or absence detection** | $F_{OC}$ |
|---|---|
| Manual On / Off Switch | 1,00 |
| Manual On / Off Switch<br>+ additional automatic sweeping extinction signal | 0,95 |
| **Systems with automatic presence and/or absence detection** | $F_{OC}$ |
| Auto On / Dimmed | 0,95 |
| Auto On / Auto Off | 0,90 |
| Manual On / Dimmed | 0,90 |
| Manual On / Auto Off | 0,80 |

Installations that respond to absence in offices often make use of luminaire dimming capability. For instance, centralised automatic sweeps in offices can switch off all lights in the office after working hours, but they can also lower the lighting intensity to 10 or 20% for the entire area. This responds to a general demand of users to avoid completely dark offices. Incorporation of dimming capability within absence control can therefore greatly influence the energy–efficiency of the installation. In open plan offices it is assumed that presence detection is always performed on dimming instead of complete switching off, in order not to disturb occupants in other areas.

**Calculation and values used for this study:**
The Fo factor can be calculated using lighting design software based on the EN 15193 standard, such as Dialux. It uses the Occupancy dependency factor (Foc) (see Table 3-1) and Absence factor(Fa) calculation methods defined in the standard. The Absence factor is 0.3 for a "cellular 2-6 person office", 0 for "open plan offices with detector range > 30m²" and 0.2 for "open plan offices with detector range < 10m²". In Task 4 a spreadsheet incorporating part of the EN 15193 calculation will be made available, stakeholders who are interested to contribute can ask for it.

#### 3.2.1.2.3 Daylight Dependency Factor (Fd)

*A **Daylight Dependency Factor** (**Fd**) is defined in EN 15193 to model the impact of daylight on artificial lighting energy consumption.*

**Approach:**
This is a correction factor on the operational hours as a function of: climate, latitude, daylight factor for sun shading not activated in relation to glazing and orientation, daylight supply factor for sun shading activated in relation to daylight availability and the type of blind control and type of daylight-responsive control systems.

Daylight supply in EN 15193 depends on the so-called *Daylight Factor(D)*. This standards classifies daylight availability as a function of the daylight factor, see Table 3-2. The daylight factor should reflect 'the mean value of the daylight measured on the axis running parallel to the respective façade section and at a distance of half the space depth from the façade'. A Daylight Factor herein is defined as the ratio of the light level inside a structure due to daylight versus the light level outside the structure (i.e. 10000 lux), as a consequence 2 % means 200 lx. Daylight factors are calculated with a standardized sky (CIE sky No 1), which represents an overcast sky with diffuse daylight. This means that such calculations are independent of the orientation of the building.

*Table 3-2 Daylight classification as a function of daylight factor (source: EN 15193)*

| Classification of daylight availability depending on Daylight Factor of the raw building carcass opening | |
|---|---|
| DF ≥ 6 % | Strong |
| 6 % > DF≥ 4 % | Medium |
| 4 % > DF ≥ 2 % | Low |
| DF< 2 % | None |

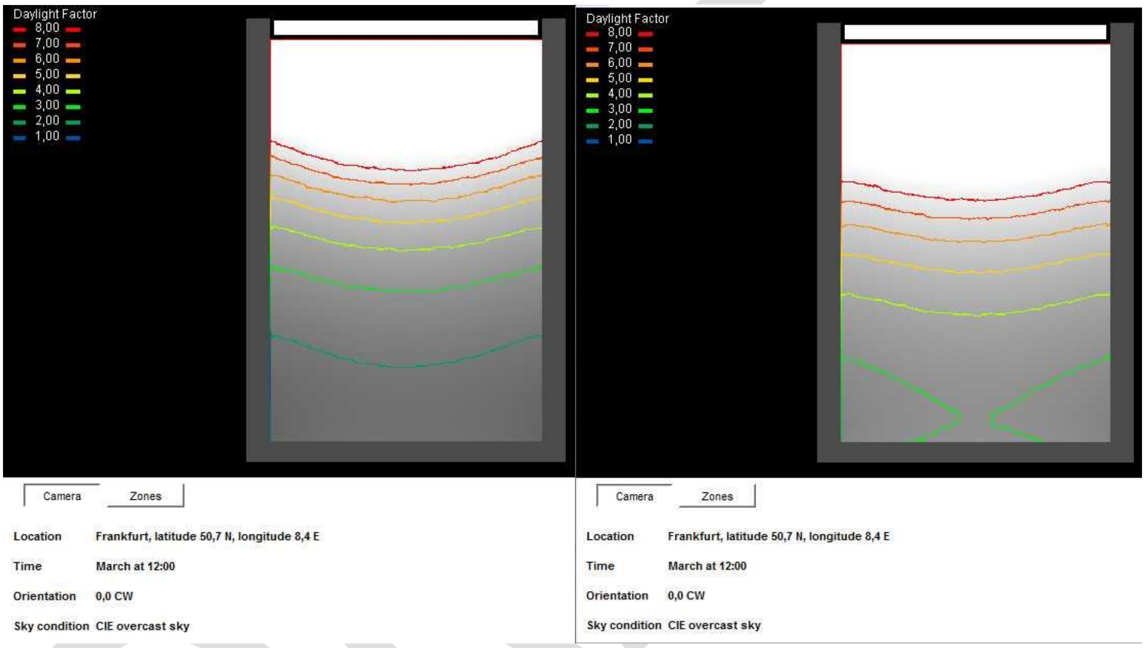


*Figure 3-7 Daylight Factor calculations[149], left for a cellular office with standard reflection coefficients (ceiling=0,7; wall=0,5; floor=0,2) and right for bright reflection coefficients ((ceiling=0,84(white matte); wall=0,71 (beige); floor=0,59(linoleum))*

149 VELUX Daylight Visualizer software (validated with CIE 171:2006), free available at http://www.velux.com/

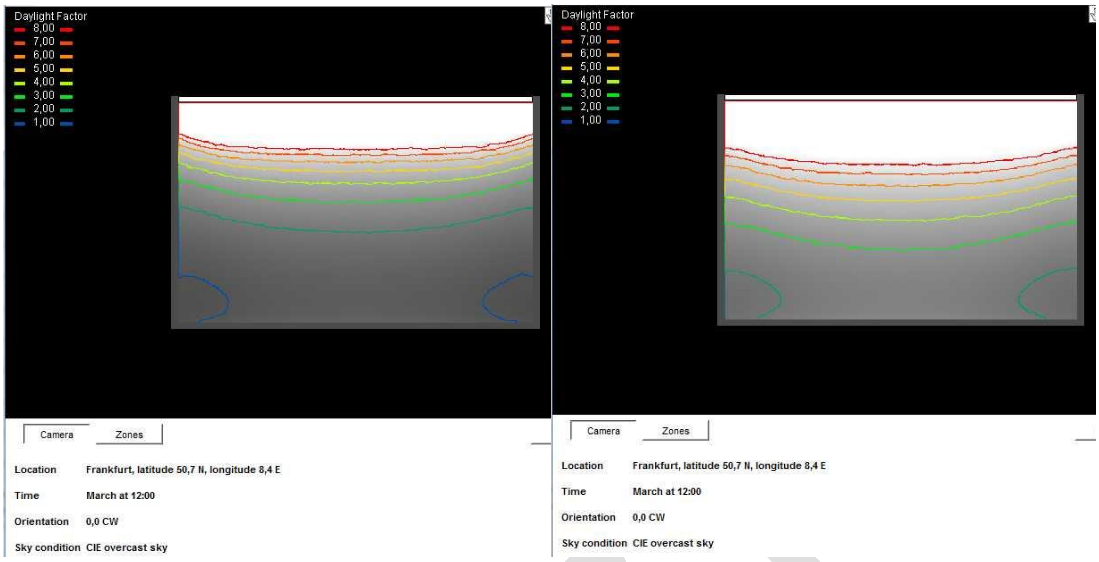


*Figure 3-8 Daylight Factor calculations , left for a open plan office with standard reflection coefficients (ceiling=0,7; wall=0,5; floor=0,2) and right for bright reflection coefficients ((ceiling=0,84(white matte); wall=0,71 (beige); floor=0,59(linoleum))*

Taking into account the daylight availability and the type of blind control the standard EN incudes different types of daylight to calculate a so-called *daylight supply factor* (Fd,s), for vertical facades with sun shading see Table 3-3.
The types of blind control (annex F) (EN 15193) to calculate a daylight supply factor ($F_{d,s}$) are (see also section 1.3.2.3.1):

- "MO" (Manual operated): glare protection only - systems which provide glare protection in compliance with the regulations applying to the respective utilization profile, e. g. regulations for computer terminal workplaces. This includes manually operated venetian blinds and semi-transparent fabric sun-screens.
- "Auto" (Automatic): automatically-operated protection against solar radiation and glare - devices to protect against solar radiation and/or glare and which can be moved in relation to the amount of daylight available. Venetian blinds which are automatically opened slightly after being lowered, so that transmittance is greater than that of the fully-closed blinds.
- "Guided": light-guiding systems (examples would be useful in Task 4).
- "None": No protection against solar radiation and shades. (NOTE only applicable for areas being evaluated for which no special regulations or provisions such as the regulations for computer terminal workplaces apply.)

*Table 3-3 Determination of daylight supply factor($F_{d,s}$) for sun shading activated (source: EN 15193)*

| | Classification of daylight availability | | | |
|---|---|---|---|---|
| control type | None | Low | Medium | Strong |
| | D<2% | 2%≤D<4% | 4%≤D<6% | D≥6% |
| MO | **0** | **0,1** | **0,2** | **0,3** |
| Auto | **0** | **0,2** | **0,43** | **0,55** |
| Guided | | **0,3** | **0,65** | **0,8** |
| None | | **0,3** | **0,65** | **0,8** |

Also daylight responsive control systems will have an impact on energy use, this can be done with the so-called *daylight dependent control factor* ($F_{d,c}$) in function of availability of daylight, target illumination level and type of control system. This can be calculated according to EN 15193, as illustrated in Table 3-4. The different types of daylight-responsive control systems (annex F) (EN 15193) to calculate a *dependent control factor* ($F_{d,c}$) are (see definitions in section 1.3.2.3.1):

- "Manual control" (Type I), means the users controls the on:off switch.
- "Automatic On/off"(Type II), means the electric lighting is automatically switched off when the maintained illuminance is achieved by daylight at the point where the illuminance is measured. The electric lighting is switched on again automatically when the maintained illuminance is no longer achieved by daylight.
- "On/off in stages" (Type III), means the electric lighting is switched off in stages until the maintained illuminance is achieved by daylight at the point where the illuminance is measured. The electric lighting is switched on again automatically in stages when the maintained illuminance is no longer achieved by daylight.
- "Daylight responsive off" (Type IV), means the electric lighting is switched off when the maintained illuminance is achieved by daylight at the point where the illuminance is measured. The electric lighting has to be turned on again manually.
- "Stand-by losses, switch-on, dimmed" (Type V), means the electric lighting is dimmed to the lowest level during usage periods (periods with adequate daylight) without being switched off (i.e. it uses electrical power ("stand-by losses")). The electric lighting system is turned on again automatically.
- "No stand-by losses, switch-on, dimmed" (Type VI), means the electric lighting is switched off and turned on again ("dimmed, no stand-by losses, switch-on"). The electric lighting is dimmed to the lowest level during usage periods (periods with adequate daylight) and switched off (i.e. no electrical power is used). The electric lighting system is turned on again automatically.
- "Stand-by losses, no switch-on, dimmed" (Type VI), means as system V, except that the electric lighting system is not turned on again automatically.
- "No stand-by losses, no switch-on, dimmed" (Type VII), means as system VI, except that the electric lighting system is not turned on again automatically.

This dependent control factor ($F_{d,c}$) is also related to the classification of daylight availability (Table F.16) which is derived from the daylight supply factor (Fd).

*Table 3-4 Correction factor $F_{d,c}$ to account for the effect of daylight-responsive control systems in a zone n, as a function of the maintained illuminance $\bar{E}m$ and the daylight supply classification (source: EN 15193)*

| Daylight availability | | Low | Medium | Strong |
|---|---|---|---|---|
| $\bar{E}$m(illuminance) | | 500 lx | 500 lx | 500 lx |
| System | Type of system | | | |
| Manual | I | 0,47 | 0,52 | 0,57 |
| On/off | II | 0,59 | 0,63 | 0,66 |
| On/off in stages | III | 0,7 | 0,73 | 0,75 |
| Daylight responsive off | IV | 0,7 | 0,73 | 0,75 |
| Stand-by losses, switch-on, dimmed | V | 0,7 | 0,73 | 0,75 |
| No stand-by losses, switch-on, dimmed | VI | 0,74 | 0,78 | 0,81 |

| | | | | |
|---|---|---|---|---|
| Stand-by losses, no switch-on, dimmed | VII | 0,77 | 0,8 | 0,83 |
| No stand-by losses, no switch-on, dimmed | VIII | 0,81 | 0,86 | 0,89 |

Finally, the Daylight Dependency Factor ($F_d$) is calculated from the daylight dependent control factor ($F_{d,c}$) and the daylight supply factor ($F_{d,s}$) with the following formula:

$F_d = 1 - F_{d,c} \times F_{d,s}$

**Background:**
The exact calculation of daylight savings is dependent on: local weather conditions, the building's construction, types of blind used and the control systems used. The calculation of daylight availability is documented in the EN15193 standard for various configurations and conditions.

Due to seasonal differences the monthly energy consumption for artificial light with daylight contribution will vary. Therefore the standard contains 'Monthly distribution key factors for vertical façades' (Annex F). These factors can also be used to calculate the indirect effects of lighting on the building energy balance for the cooling and/or heating load per month, see section 3.3.

**Calculation and values used for this study:**
The Fd factor can be calculated based on the EN 15193 standard or by lighting design software based on this standard, such as Dialux.
For the reference offices according to calculations, seeFigure 3-7and Figure 3-8 the following daylight availability classes will be used:

- Cellular office with standard reflection coefficients: medium daylight availability.
- Cellular office with bright reflection coefficients: strong daylight availability.
- Open plan office with standard reflection coefficients: low daylight availability.
- Open office with standard reflection coefficients: medium daylight availability.

The impact can vary according to the choosen solar blind and daylight control system, see Table 3-3 and Table 3-4.

#### 3.2.1.2.4 Constant illuminance Factor (Fc)

*A **Constant illuminance Factor** (**Fc**)r is defined in EN 15193 to model the impact of smart dimming control designed to constantly match the illuminance to the required minimum.*

**Approach:**
This is a correction factor on the consumed power as a function of the maintenance factor ($F_M$) and the type of control.

**Background:**
All lighting installations, from the instant they are installed, start to decay and reduce their output. Therefore EN 12646 specifies the task illuminance in terms of maintained illuminance and in order to assure conformity the scheme should provide higher initial illuminance. As a consequence the decay rate is estimated in the design of the lighting scheme and applied in the calculations, which is known as the maintenance factor ($F_M$), see later section 3.2.1.3. A smart constant illumination control system increases the power over time to keep the luminous flux constant based upon the known lumen depreciation of the light source (no external sensors involved). Hence it will provide additional energy saving because less power is consumed in the beginning - the EN 15193 standard provides formulas to calculate these savings.

Apart from the maintenance factor other factors can also contribute to over illumination, such as over specifying the number and output of luminaires, and such a control can compensate for this and save power. Other examples are: variations in room reflection coefficient, see section 3.2.1.4, and/or a discrete number of light points and their maximum light output that always need to surpass the minimum requirement, see section 3.2.1.5.

**Calculation and values for this study:**
The FC factor can be calculated based on the EN 15193 standard. In Task 4 a spreadsheet incorporating part of the EN 15193 is available on request for stakeholders who want to contribute and verify.

### *3.2.1.3 Influence of maintenance factors (FLM, FLLM, FRSM)*

*The EN 12464 standard series specifies requirements in terms of 'Maintained illuminance' (Em), which is a value below which the average illuminance on the specified area should not fall. Therefore, for compliance, the planner or designer needs to establish and document how much the luminous flux of a lighting installation will decrease by a certain point in time and recommend appropriate maintenance action. Therefore an overall* ***maintenance factor*** *(**FM**) is defined.*

**Approach:**
This can be done based on the maintenance factor (FM), and the room surface maintenance factor (FRSM) as defined in Task 1.

The overall maintenance factor (FM) can be calculated as follows:

FM = FLM x FLLM x FRSM (assuming spot replacement, see section 3.4.4)
Wherein,
FLM = Luminaire maintenance factor (see Task 1)
FLMM = Lamp Lumen Maintenance Factor (see Task 1)
FRSM =Room surface maintenance factor(see Task 1)
FM = FLS x FLM x FLLM (assuming no spot replacement, see section 3.4.4)
With,
FLS = Lamp Survival Factor (see Task 1)

All factors are dependent on the frequency of the maintenance cycle, see section 3.4.4.

For LED luminaires the factors FM and FLS are not directly available from the standard data but can be calculated from other data available in catalogues according to IEC 62717 and with a guideline provided for conversion of those parameters[150]:
LLMF is obtained from manufacturers' light degradation curves for the relevant observation period, but is based on the LED module rated life, Lx (IEC 62717) (see Task 1).
FLMM = Lx
Wherein,
Lx = length of time during which a LED module provides more than the claimed percentage x of the initial luminous flux, under standard conditions (see Task 1)/ Lx values at F50 will be used, hence accepting a luminaire failure fraction of 50 % on the percentage x of the initial luminous flux (IEC 62717)
at their rated life designates the percentage (fraction) of failures .

[150] ZVEI (2013): 'Guide to Reliable Planning with LED Lighting Terminology, Definitions and Measurement Methods: Bases for Comparison'

**Background:**
The Luminaire Maintenance Factor, Lamp Survival Factor, Lamp Lumen Maintenance Factor and Room Surface Maintenance Factor are related to the maintenance cycle of existing installations (CIE 97(2005)).
High maintenance factors are beneficial and can be achieved by careful choice of equipment and electing to clean the installation more frequently. ISO 8995/CIE S 008-2001 recommends selecting solutions so that the maintenance factor does not fall below 0.7.

FLS and FLLM values are based on data supplied by luminaire manufacturers.

Research in France[151], [152] showed that with regard to the "Replacement strategy for fluorescent tubes" only 20% of the premises systematically replace all the tubes of a set of fluorescent lamps when only one of the tubes fails. Only 1 out of the 50 establishments in the sample had a preventive maintenance policy which comprised a systematic replacement of all the fluorescent tubes and starters of this building each year. Furthermore 75% of the investigated establishments systematically replaced the fluorescent lamp starters at each replacement of a tube.
The SAVE report "Market research on the use of energy efficient lighting in the commercial sector"[153] gathered information on the frequency of inclusion of cleaning of luminaries during maintenance in offices, as presented in Table 3-5. It revealed that office lighting luminaires were only cleaned regularly in Spanish and private Greek offices.

Table 3-5: Frequency of inclusion of cleaning of luminaries during maintenance[153]

| Frequency % | | Total number (n) | No | Yes | n/a[154] |
|---|---|---|---|---|---|
| **Belgium** | public | 277 | 28,9 | 0 | 71.1 |
| **Denmark** | public | 494 | 2 | 1 | 97 |
| | private | 208 | 14 | 24 | 63 |
| **Spain** | public | 144 | 12.5 | 74.3 | 13.2 |
| | private | 122 | 8.2 | 69.7 | 22.1 |
| **Greece** | public | 354 | 92.9 | 1.4 | 5.7 |
| | private | 246 | 42.3 | 45.5 | 12.2 |
| **Italy** | public | 257 | 0 | 0 | 100 |
| | private | 348 | 60 | 19 | 21 |
| **UK** | Public/private | 50 | 100 | 0 | 0 |

**Calculation and values used for this study:**
A value of $F_{RSM}$ =0.96 will be assumed based on (CIE97(2005)) Tables 3.6 & 3.7 with the typical 0.7/0.5/0.2 reflectance's in office surfaces with a regular cleaning cycle of at least two times per year.

[151] Enertech, 2004. Technologies de l'information et d'éclairage: Enquêtes de terrain dans 50 batiments de bureaux
[152] Enertech, 2005. Technologies de l'information et d'éclairage: Campagne de mesures dans 49 ensembles de bureaux de la région PACA
[153] DEFU, 2001. Market research on the use of energy efficient lighting in the commercial sector. SAVE report.
[154] No answer

A value of FLM = 0.96 will be assumed because the indicative benchmark in regulation EC 245/2009 specifies that 'Luminaires have a luminaire maintenance factor LMF > 0.95 in normal office pollution degrees with a cleaning cycle'.
The FLS and FLLM values are based on data supplied by luminaire manufacturers (see Task 4). Sometimes manufacturers only supply a single value per luminaire, e.g. L80F50 is 50000 h, and therefore tables[155] or tools are needed to extrapolate values for the application. Stakeholders are invited to supply such[155] tools.

#### *3.2.1.4 Use parameters influencing the lighting system utilance*

***The Utilance*** *(**U**) of an installation for a reference surface (see Task 1) is defined as the ratio of the luminous flux received by the reference surface to the sum of the individual total fluxes of the luminaires of the installation (IEC 50/CIE 17.4). It is a metric for the efficiency of the lighting installation to convert luminaire lumens into illuminance in the task area.*

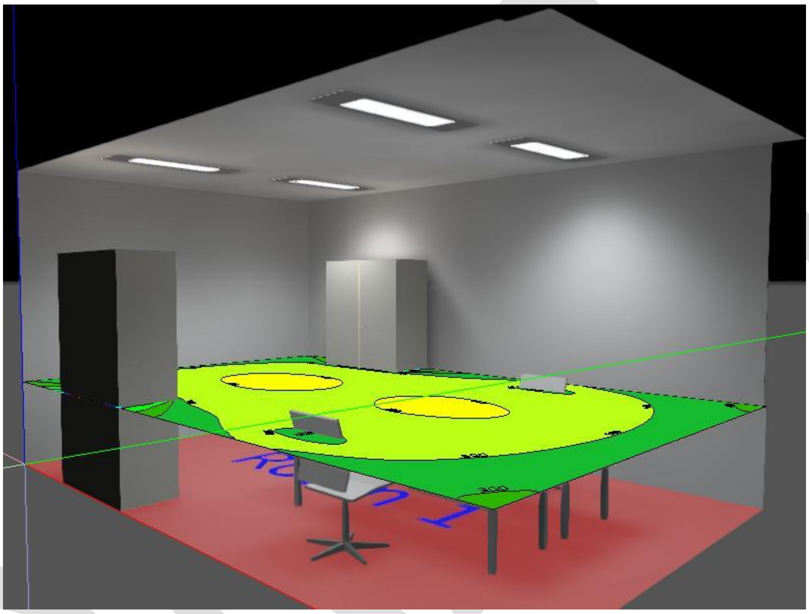

*Figure 3-9 Utilance for indoor lighting can be obtained from lighting design calculations[156].*

**Approach:**
It can be calculated analytically from the geometry, room reflectance and CEN flux code in accordance with EN 13201-2 (see Task 1) or with lighting design software (Figure 3-9) with the following formula:

U = Em/( Φ x A)

Wherein,
Φ = Rated luminous flux
Em = Maintained illuminance
A = Task Area

**Background:**
Impact of office room area size and light point location

[155] Zumbtobel, The Lighting Handbook, p.252, http://www.zumtobel.com/
[156] Simulation done by Dialux Evo: www.dial.de

Local infrastructure and room design can have a large effect on the efficiency of lighting installations. Office zone lay-out can influence lighting design, e.g. individual or cellular offices allow more dimming options for energy saving compared to open plan offices with cubicles. Also the reflection of walls is larger in cellular offices compared to open plan offices. In order to analyse the influence of this factor on lighting system energy consumption a set of typical room types are defined in this study: a cellular office and an open plan office.

Impact of room surface reflection

The room surface reflection also has an influence on the illumination of the task area. The most common default or typical room reflectance values[157] are included in Table 3-6 below, they can be used for photometric calculations.

The exact surface reflection is not always known during the design of the installation and can also change during use, therefore default values are commonly used in photometric calculations. But this can lead to over or under dimensioning of the illumination in rooms with bright or dark surfaces, therefore these extreme values are also included. It is important to note that products that are adaptable to variable room reflectance conditions by including dimming ballasts can tune the illumination level close to the minimum required. Also furniture can have an impact on real performance, see Figure 3-9. High reflectance values are also beneficial for increasing the use of daylight, see section 3.2.1.2.3. The very bright values in Table 3-6 are sourced from Table 3-3 and based on reference data from daylight calculation software[149].

*Table 3-6: Reflectance values used in this study*

| | very bright | typical (default) | very dark |
|---|---|---|---|
| Ceiling reflectance | 0.84(e.g. white matte) | 0.7 | 0.5 |
| Wall reflectance | 0.71 (e.g. beige) | 0.5 | 0.3 |
| Floor cavity reflectance | 0.59 (e.g. linoleum) | 0.2 | 0.2 |

What are typical dimensions of a small office room or *cellular office?*

A cellular office is often between 18 m² and 30 m² [157]. Several administrations specify net available surfaces for each office worker. Architectural standards take 10 to 15 m² per office worker into account. Usually multiples of 60 cm are used in order to fit with floor and ceiling tiles. The Belgian administration uses as a guideline 12 m² per office worker. A guide on the implementation of EN 12464 recommends that the work station area should be assumed to be 1.8 m x 1.8 m square[158] and as minimum the total office area should be much larger. As a conclusion this study proposes to select a room length of 3.6 m parallel to the window and a room depth of 5.4 m, resulting in a room size with a floor area of 19.44 m². These are the dimensions of the cellular offices defined in sections 3.1.2.1and 0 The assumed height is based on architectural standards used in buildings from 1970 up to the present. The net height between ceiling and floor is often 2.8 m. In older buildings, this height is often higher; however, new project developments focus on a maximum number of building floors for economic reasons and therefore a ceiling height of 2.8m is considered to be representative.

The selected room depth takes into account the maximum depth of the daylight area defined in EN 15193 as 2.5 times the maximum window height of 2.8 metres minus the typical height of an office desk (0.8 m) which results in 5 metres. The formula from the standard EN 15193 is an important rule of thumb in building design for

[157] Fördergemeinschaft Gutes Licht. Heft 04 Gutes Licht für Büros und Verwaltungsgebäude, ISBN 3-926 193-04-02

[158] Licht.de: Guide to DIN EN 12464-1, ISBN-No. PDF edition (English) 978-3-926193-89-6

defining maximum room depths with sufficient daylight in buildings. As a consequence the typical office depth is rarely much more than 6 metres.
An important trend due to the increased cost of buildings per square meter is to have more workers per area, up to 1 per 6 m² instead of 1 per 12 m² as suggested before. Technically this is possible by installing mechanical ventilation, air conditioning, reduction of the total office area close to the minimum work station area (1.8m x 1.8m) and working as in as paperless a manner as possible without cabinets. In our reference cellular application office defined in sections 3.1.2.1 and 0 we will therefore assume two office workers.

<u>What are typical dimensions of a large office room or *open plan office?*</u>
Open plan or group offices are also evaluated in this study. Open plan offices are typically used by groups of from 10 to 30 office workers. The dimensions of the reference open plan application in sections 3.1.2.3 and 3.1.2.4 were selected by multiplying the dimensions of the cellular office application by a factor 3 but with a window at the longest side. This results in an office area of 175 m², that can typically host 24 workers (see Figure 3-4)
Generally, in these offices it is beneficial to use a slightly increased ceiling height in order not to create a very shallow floor to ceiling appearance, therefore an office ceiling height of 3 meters was chosen.

Methods for increasing the Utilance will be discussed in Task 4.

**Calculation method and values used for this study:**
The Utilance will be calculated with lighting design software and the Flux code method (EN 13032-2).

#### 3.2.1.5 Luminaire installation and matching of the minimum lighting design requirements for the task area

*Over-lighting compared to the minimum required illuminance will also contribute to energy losses. This effect has been modelled in road lighting (in standard prEN 13201-5) and will be modelled using a similar approach here. Therefore a **correction factor for over-lighting**(**Fc**) is defined.*

**Approach:**
The correction factor for over-lighting, $Fcl=C_L=Em,min/Em$ as defined in Task 1.

**Background:**
<u>Selecting the correct number of luminaires to closely match the minimum required illumination:</u>
Luminaires are sold in discrete numbers with stepwise changing lumen outputs, and therefore tend to be over-dimensioned in order to satisfy the minimum illumination requirements. For example the luminaire grid needs to fit with the ceiling design, and it may only be possible to install 3 or 4 luminaires but nothing in between. Dimmable luminaires with constant illumination control can address this problem by lowering the light output, see section 3.2.1.2.4.
<u>Over-dimensioning task areas with high illuminance requirements:</u>
The standard EN 12464-1 requires that 'for places where the size and/or location of the task area is unknown, the area where the task might occur shall be taken as the task area' while illuminance requirements for the surrounding area in office lighting are only 300 lx compared to 500 lx for the task area.
In consequence energy can be saved by providing dimming capabilities to luminaires in order to adapt their output in use to the exact office desk location.
The following parameter can be used in the assumption that 1/3 of the area can be dimmed from 500 to 300 lx: BGF = 1/(1-0.33x200/500) = 1/0.87 = 1.15.

**Calculation method and values used for this study:**
The Em, min can be sourced from the EN 12464 standard and Em can be calculated with lighting design software and the Flux code method (EN 13032-2).

#### *3.2.1.6 Luminaire and lamp efficacy parameters*
Please consult the complementary light source study[159] (lot 7) which addresses this topic.

### 3.2.2 Energy consumption of indoor lighting system in the use phase not yet covered in prEN 15193
*The performance parameters defined in chapter 1 are obtained under standard test conditions, however in real life these parameters may deviate from these values. Hereafter we will discuss the factors that can influence the energy consumption of luminaires and their control systems in real life, for example: temperature, line voltage...*

**Approach:**
An extra parameter (see definition in chapter 1) could be defined which enables additional corrections on energy consumption:
**BMF**: **Ballast Maintenance Factor**

**Background:**
Temperature effect:
Lamp efficacy and hence power consumption of fluorescent lamps are influenced by temperature[148]. As with fluorescent lamps in general, the rated luminous flux for T5 HE and T5 HO fluorescent lamps is specified at 25 °C, and T5 HE and T5 HO lamps achieve their maximum luminous flux at temperatures between 34 and 38 °C. One of the advantages of T5 lamps is therefore an increased luminaire light output ratio (RLO).
In this study we assume the appropriate constant environmental temperature for office lighting applies.
Line voltage effect:
Power consumption and light output of gas discharge lamps vary with line voltage when a magnetic ballast is used: typically giving a +/- 20 % power variation with a +/- 10 % variation of line voltage. Line voltage variations of up to +/- 10 % are allowed and also not exceptional in the public grid. Electronic ballasts used in office lighting can overcome this problem. They incorporate electronic Power Factor Compensation (PFC) circuits that need to be used for ballast power levels above 25 W in order to satisfy standard EN 61000-3-2 [160]. The most commonly used active electronic PFC topologies are independent of the line voltage[161].
Lamp voltage effect:
Power consumption and light output of gas discharge lamps also vary with lamp voltage when a magnetic ballast is used. Lamp voltage can vary with production variations and generally increases with aging. Some electronic ballasts have an internal power control loop and are independent of the lamp voltage, they even detect 'end-of-life' when lamp voltage becomes excessive. This is also the case with LEDs, see the Lot 8/9/19 light source study[148].
Low Power factor impact:

[159] http://ecodesign-lightsources.eu/
[160] Basu (2004), Supratim Basu, T.M.Undeland, PFC Strategies in light of EN 61000-3-2, EPE-PEMC 2004 Conference in Riga, LATVIA, 1- 3 September 2004
[161] Garcia, (2003), Single phase power factor correction: a survey, IEEE Transactions on Power Electronics, volume 18, issue 3, May 2003.

The power factor of an AC electric power system is defined as the ratio of the real power to the apparent power and is a number between 0 and 1. Real power is the capacity of the circuit for performing work in a particular time. Apparent power includes the reactive power that utilities need to distribute even when it accomplishes no useful work. Low-power-factor loads increase losses in a power distribution system and result in increased energy costs (LRC (1995)). There is no direct limitation on power factor of luminaires at product level. However many power distribution companies have penalties for large consumers when the total power factor is below 0.8. Therefore many luminaire manufacturers incorporate this feature in luminaires. This feature is always incorporated in electronic ballasts with power levels above 25 W, because an active power factor compensation (PFC) circuit is needed in order to satisfy the harmonic current limits of standard EN 61000-3-2 (Basu (2004)). In consequence, electronic ballasts with power factor compensation (all above 25 W) outperform magnetic ballasts.

Power factor compensation and capacitor ageing:

Power factor compensation capacitors are used with magnetic ballasts. The capacitance decreases with capacitor age. Poor performance of the capacitor causes an increase of reactive currents and causes additional power losses in the cables of the distribution grid. According to a study by ADEME (2006) up to 9% of additional energy losses can be caused in the distribution grid by aged capacitors with a poor power factor.

High level of harmonic line currents:

Discharge lamps cause harmonic currents that cannot be compensated in magnetic ballasts[162]. The level of harmonic current on the line voltage when using magnetic ballasts can vary from 8 to 13 %. In particular, third harmonic currents (which are limited under EN 61000-3-2) can cause increased magnetic losses in distribution transformers and in the neutral wire[163]. Electronic ballasts with pure sine wave electronic power factor corrector (PFC) circuits overcome this problem. This feature is always incorporated in electronic ballasts with power levels above 25 W, because an active Power Factor Compensation (PFC) circuit is needed in order to satisfy the harmonic current limits of standard EN 61000-3-2 [160]. As a consequence electronic ballasts (of > 25 W) with power factor compensation outperform magnetic ballasts.

Colour and Vision:

TBW

Weather conditions:

When daylight responsive control systems are involved, the daylight harvesting is related to the weather conditions. These may deviate from the predicted or assumed conditions and also vary across Europe. The standard EN 15193 includes for different locations default weather conditions but for this study a single standard location (Frankfurt) was chosen because of its central location in Europe.

Working hours and office occupancy:

User behaviour, including occupancy, is often hard to predict and the standard works with default hours per type of area and/or activity.

**Conclusions and values used for this study:**

It is proposed to neglect conduct of an assessment within this study of the losses associated with deviations in the operating conditions of luminaires from those specified in the standard discussed because more precise data and evidence is missing and also taking these effects into account is not common practice.

[162] Chang (1993), Chang, Y.N.; Moo, C.S.; Jeng, J.C, Harmonic analysis of fluorescent lamps with electromagnetic ballasts, IEEE Region 10 Conference Proceedings on Computer, Communication, Control and Power Engineering, 1993.

[163] IESNA, 1995. Lighting Handbook, Eighth Edition, ISBN 0-87995-102-8, p.215

With respect to the assumptions regarding the working or operating hours, however, a sensitivity analysis could be done in Task 7 to assess the impact on Life Cycle Cost, although data for this is still missing.
Weather conditions, currently taken from Frankfurt (Lattitude 50,0°), can also be modified to Stockholm (Lattitude 59.7°) and Athens(Lattitude 37.9°) in a sensitivity analysis to be done in Task 7.

### 3.2.3 Energy consumption of road lighting in the use phase according to EN 13201-5

#### 3.2.3.1 Energy of road lighting systems according to EN 13201

Formulas are also introduced in Task 1, see Figure 1-2 and the relevant part is included in Figure 3-10 . The most important Annual Energy Consumption Indicator (PE = AECI, prEN 13201-5) which represents the annual energy consumption(kWh) per square meter but also the installation efficacy can be calculated (lm/W) and lighting power density (DP).

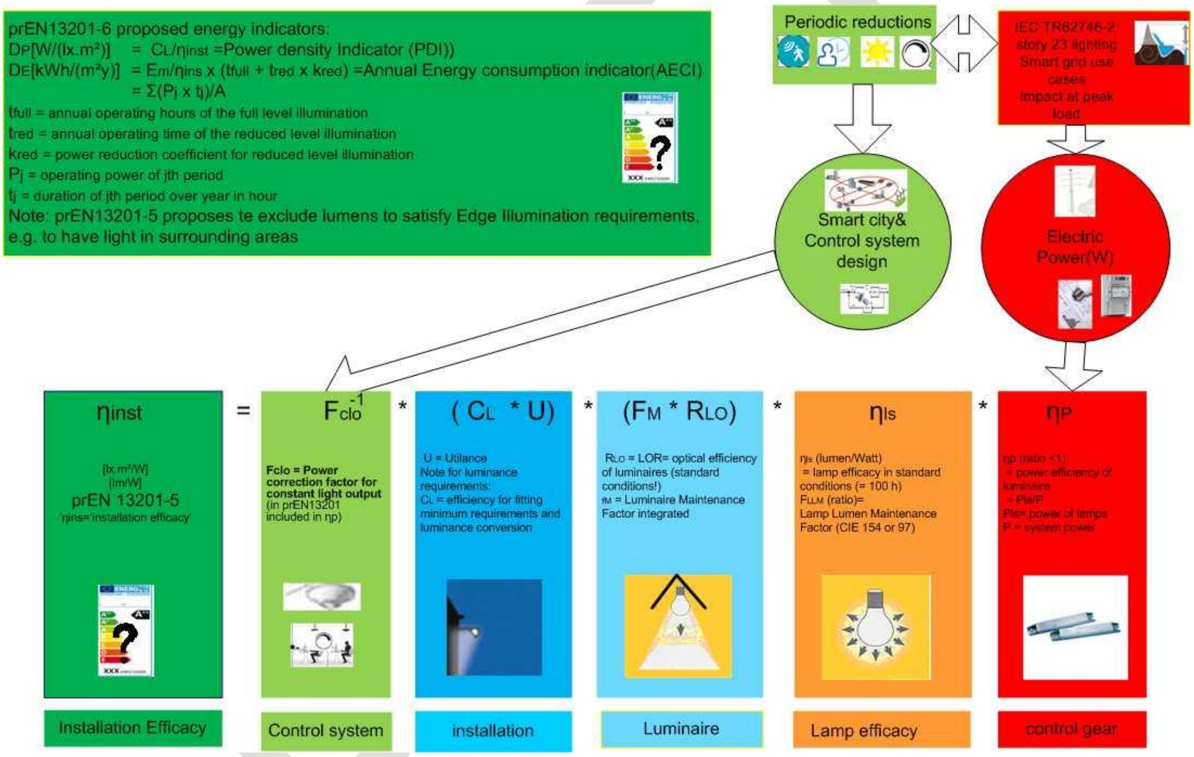


Figure 3-10 Formulas for modelling energy consumption in road lighting lighting

#### 3.2.3.2 Use parameters influencing lighting system control

##### 3.2.3.2.1 Day time, night time and road traffic dimming

*Daylight and smart dimming as a function of traffic and weather conditions can contribute to energy savings. Therefore operating times(**tfull, tred**) and a reduction coëfficient for dimming(**kred**) are defined.*

**Approach:**
For modelling this effect EN 13201-5 defines:

**tfull** = annual operating time at full illumination level (h)
**tred** =annual operating time at full illumination level (h)
**kred** = reduction coefficient for the illumination level (h)

**Background:**
Globally the dark period is 4000 h per year. Seasonal changes between winter and summer increase with distance from the equator. Nordic countries have daylight during almost the whole day in summer and are dark (almost) all day in winter. At equinox (21 March and 21 September) day and night periods are equal everywhere over the globe. As a consequence 4000 operating hours per year is the universal default value for street lighting. Switching off street lighting later in the night is rarely applied and there are several arguments why this is the case as explained below.
Public lighting requirements are traditionally dominated by road traffic safety concerns and the perceived security feeling especially in densely populated areas. The absolute *reduction of crime* by public lighting is not proven and is controversial. Several studies show that lighting can displace criminality from higher lit places to lower lit places[164].
Switching off 50 % of the lamps in alternating patterns causes poor uniformity in the illumination of the street, one of the important performance requirements for public lighting, a better alternative is dimming each luminaire.
The Expert inquiry of lot 9 (2007) sent out to all stakeholders showed that complete or partial switch off is rarely applied in the 25 EU-countries, and is probably only used for a maximum of up to 5% of the EU's roads.
One reason why this is the case might be that the lamp survival factor of a discharge lamp is negatively influenced by the number of switching cycles during its lifetime, due to the high voltage peak that the ignitor generates to start the lamp. If the number of switching cycles is doubled the normal lifetime of a discharge lamp is shortened by 30%.
Dimming related to traffic density is rarely done but the method is included in guideline CEN/TR 13201-1, in this case traffic density should be interpreted on an hourly basis and light levels could be adapted accordingly. This new practice is not yet incorporated in this guideline and traffic density is expressed on a daily basis resulting in one road class connected to a particular road. It is also clear that road classes with high light levels selected on a daily basis can benefit more from dimming compared to lower level classes. One objective of the 'E-street' SAVE project was to contribute to the development of standards and guidelines adapted to intelligent dimming. Work group CIE 40.44 is working on this subject.

Dimming related to local weather conditions is also rarely done and limited data is available, therefore the lot 9 study assumed a minimum saving of approx. 5% only when stepwise electronic dimming ballasts are provided.

**Values used for this study:**
The proposal for this study is to use the following default values:
tfull = 4000 h
tred = 0 h
kred = 0
In Task 4 more appropriate schemes that include dimming will be investigated.

#### 3.2.3.2.2 Constant illumination control (Fclo)

*Constant light output (CLO) control of a road lighting installation aims to provide a constant light output from the light sources. Therefore the **constant light output control factor*** (**Fclo)** is defined.

[164] Narisada K. & D. Schreuder (2004), Light pollution handbook., Springer verlag 2004, ISBN 1-4020-2665-X

**Approach:**
The approach proposed in this study is to follow the same approach as suggested for indoor lighting in section 3.2.1.2.4, hence:

Fclo = Fc

**Background:**
*Smart dimming to compensate for Lamp Lumen Maintenance Factor (FM):*
See section 3.2.1.2.4.
*Smart dimming to fine tune to local parameters and avoid over-lighting:*
This function allows adjustment to the minimum required light level when using the standard available wattages with their stepwise changing lumen outputs, for example: luminaire with a 70 W HPS versus 100 W HPS lamp. New dimming electronic control gear enables the maximum lumen output to be set according to the minimum illumination required.

**Calculation and values used for this study:**
For non-dimming systems we assume that this results in 10% over-lighting (see lot 9).
For smart dimming systems it is assumed that the light output is matched to the minimum requirements.

### 3.2.3.3 Influence of maintenance factors (FLM, FLLM, FRSM)

See section 3.2.1.3 for definition and approach.

**Calculation and values used for this study:**
According to the benchmark formulated in EC Regulation 245/2009, luminaires should have an optical system that has an ingress protection rating as follows:
— IP65 for road classes M
— IP5x for road classes C and P.
The corresponding maintenance factor (FM) is sourced from standard CIE 154 (see Task 1) based on the maintenance cycle and the ingress protection.
FLS and FLLM values are based on data supplied by luminaire manufacturers (see Task 4).

### 3.2.3.4 Use parameters influencing the lighting system utilance

*The **Utilance (U)** of an installation for a reference surface (see Task 1) is defined as the ratio of the luminous flux received by the reference surface to the sum of the individual total fluxes of the luminaires of the installation (IEC 50/CIE 17.4). It is a metric for the efficiency of the lighting installation to convert luminaire lumens into illuminance on the road surface.*

**Approach:**
It can be calculated analytically from the geometry with lighting design software using the following formula:

$$U = Em/(\Phi \times A)$$

Wherein,

$\Phi$ = Rated luminous flux
Em = Maintained illuminance
A = Task Area

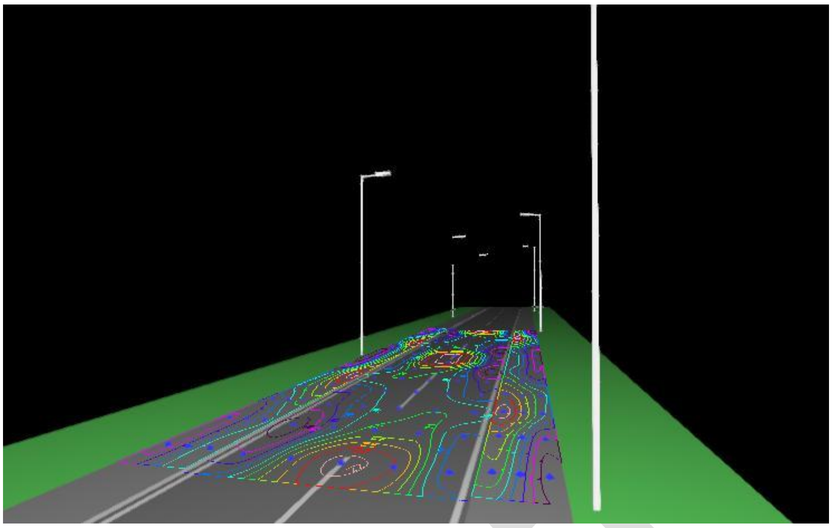

*Figure 3-11 Utilance for road lighting can be obtained from lighting design calculations[165].*

Methods for increasing the Utilance will be discussed in Task 4.

**Background:**
In street lighting the utilance is of particular importance, as it is a measure of the proportion of the light that is directed towards the area to be lit. However, not all light is directed to this area, see Figure 3-12, as sometimes light is directed towards the sky and is wasted. Even the most efficient luminaires can lead to a waste of light when they are not properly used due to wrong tilt angle orientation or the optics used in the luminaire, therefore proper lighting design and installation is important to obtain energy efficient street lighting.

*Figure 3-12: More than half of the light is directed to the sky or sea and is wasted*

Impact from road width:
The road width is an important parameter defining the road surface to be lit.

[165] Simulation done by Dialux Evo: www.dial.de

In the Lot 9 study an enquiry was sent out to all stakeholders. This is a summary of the replies:

- The received answers indicate almost the same (standardized) width for traffic lanes in the different road categories; for class M we found 3.50 to 3.75m, for class C 3.50m and for class P 2.50m to 3.00m.
- There were typically 2 traffic lanes per direction for class M roads (but sometimes 3 or 4), for class C and P there is most often 1 lane per direction.

Definition of the useful area:

Any functional lighting system is likely to cause interference with its surrounding environment because the luminaire should direct the light towards the surface or objects that need to be lit and nothing else, but this is not always the case e.g. in street lighting when light is directed toward the sky.

Lighting point spacing and spacing to height ratio (SHR):

The spacing between lighting poles or lighting points and the height of them can vary substantially.
In the lot 9 study an enquiry was sent out to all stakeholders. This is a summary of the replies:

- For the M road classes there is a very large difference in the spacing applied by EU countries, varying from 40 to 90m, although the spacing/height ratio is approximately the same: 4 (e.g. 90/20, 60/15, 48/12, 40/13). In class M there are several subclasses (M1 to M5 see EN13201) with increased illumination levels.
- For the C road classes the spacing/height ratio applied varies between 4.5 and 3 (e.g. 45/10, 50/12.5, 35/11). In class C there are several subclasses (C1 to C5 see EN 13201).
- For the P roads classes the divergence of the spacing/height ratio is between 5 and 4 (e.g. 40/8, 36/8, 25/5, 30/7, 20/4). In class P there are several subclasses (P1 to P5 see EN 13201).

It is logical that the SHR varies between the categories. In classes M and C, the European standard imposes severe limitations on the glare caused by the luminaires. This means that the luminaires cannot have wide beam light distributions and so the spacing is limited to about 4 times the height. In class P, the limitations on glare are lower and commonly lamps with smaller wattages are used so the risk of glare also decreases; implying that the luminaires can have wide beam optics and the spacing can therefore be higher. In residential areas there is generally a limitation on the pole height, but with a higher SHR the spacing can be adjusted to reasonable values.

Road Reflection for class M traffic with luminance requirements:

This is based on CIE 144(2001): Road surface and road marking reflection characteristics. This standard is required to calculate the luminance value from illumination conditions for various types of surface. This can be done with an average luminance coefficient (Q0) as defined in CIE 144: 'A measure for the lightness of a road surface being defined as the value of the luminance coefficient q averaged over a specified solid angle of light incidence' with: $Lm = Q_O \times Em$ . Typical values for Q0 are given in Table 3-7 and the expert enquiry results in Table 3-8. Please note that real road reflection can vary strongly depending on local conditions (dustiness, wetness, etc.) from -40 % up to 60 %.

*Table 3-7: Average luminance coefficient (Q0): parameter values applied in this study*

| Class | $Q_0$ | description | mode of reflection |
|---|---|---|---|
| R1 | 0.1 | concrete road or asphalt with minimum 12 % of | mostly diffuse |

| | | | |
|---|---|---|---|
| | | artificial brightener | |
| R2 | 0.07 | Asphalt (for more info see standard) | mixed |
| R3 | 0.07 | Asphalt (for more info see standard) | slightly specular |
| R4 | 0.08 | Asphalt (for more info see standard) | mostly specular |

*Table 3-8: Expert inquiry results*

| | Class M | | Class C | | Class P | |
|---|---|---|---|---|---|---|
| | % high **$Q_0$** reflection (concrete) | % low **$Q_0$** reflection (asphalt) | % high **$Q_0$** reflection (concrete) | % low **$Q_0$** reflection (asphalt) | % high **$Q_0$** reflection (concrete) | % low **$Q_0$** reflection (asphalt) |
| % | 5 | 95 | 5 | 95 | 5 | 95 |
| Typical **$Q_0$** | 0.075 | | 0.075 | | 0.075 | |

**Calculation method and values used for this study:**
The Utilance will be calculated with lighting design software in Task 4 for the reference designs discussed in section 3.1.2.

#### 3.2.3.5 Luminaire and lamp efficacy parameters

Please consult the complementary light source study[166] (lot 7).

### 3.2.4 Energy consumption of road lighting in the use phase that is not yet covered EN 13201-5

*The performance parameters defined in chapter 1 are obtained under standard test conditions, however in real life these parameters can deviate from the values derived under the standard conditions. Hereafter we will discuss four factors that can influence the energy consumption of (mainly) luminaires in real life; for example temperature, line voltage, weather conditions, traffic density, ...*

**Approach:**
The following parameter (see definition in chapter 1) could be defined:
**BMF: Ballast Maintenance Factor**

**Background:**
<u>Street lighting, colour and the sensitivity of the human eye and nature:</u>
It is important in the context of street lighting that the actual standard performance requirements on photometric values as defined in chapter 1 (lumen, lux, candela) are defined for photopic vision only. There are, however, studies that indicate that white light is optically beneficial compared to more yellowish light at similar but very low illuminance levels, when also considering scotopic and mesopic vision.
Photopic vision is the scientific term for human colour vision under normal lighting conditions during the day.
The human eye uses three types of cones to sense light in three respective bands of colour. The pigments of the cones have maximum absorption values at wavelengths of about 445 nm (blue), 535 nm (green), 575 nm (red). Their sensitivity ranges overlap to provide continuous (but non-linear) vision throughout the visual spectrum. The maximum possible *photopic* efficacy is 683 lumens/W at a wavelength of 555 nm

[166] http://ecodesign-lightsources.eu/

(yellow-green) according to the definition of the CIE 1931 standard observer[167] as illustrated in Figure 3-13. As illustrated in this figure, with 'white light' as defined in Commission Regulation (EC) No 859/2009, this maximum efficacy of 683 lm/W cannot be reached. It will depend on the definition of 'white light' and its chromacity coordinates (CIE XY), see Figure 3-13.

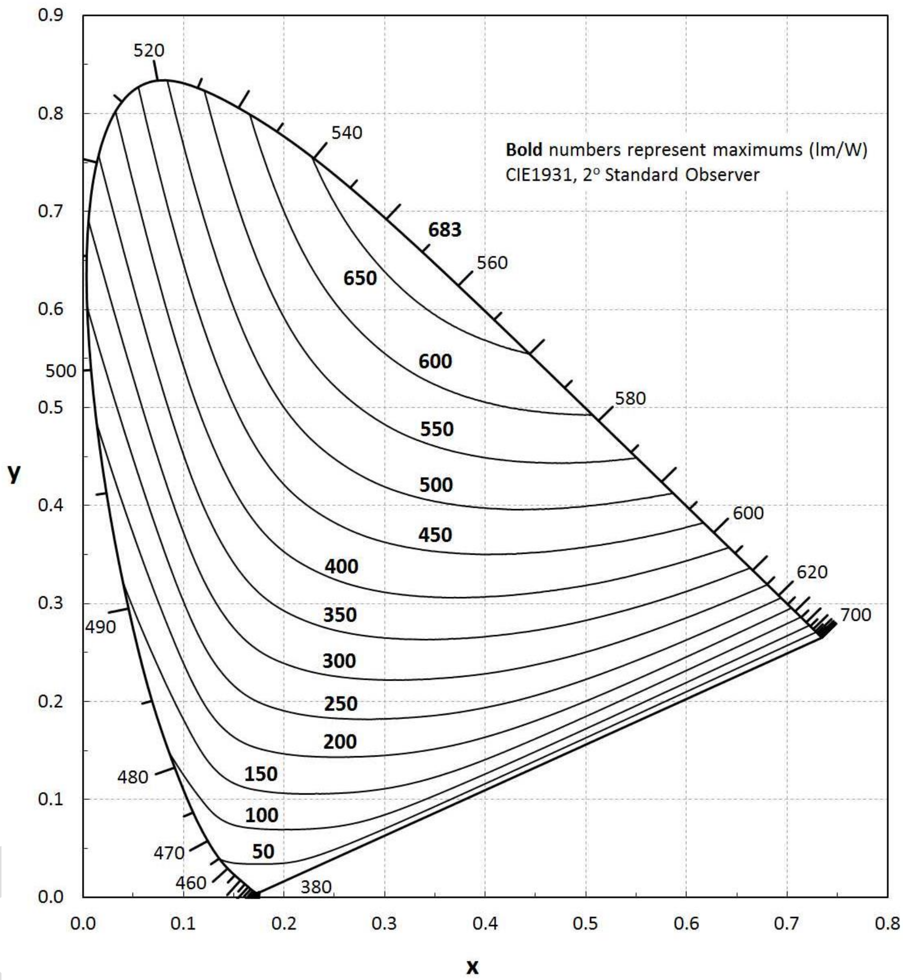


*Figure 3-13 Maximum possible luminous efficacy (lumens per watt) shown on CIE 1931 chromaticity diagram (Schelle, 2014[168])*

Scotopic vision is the scientific term for human vision "in the dark".
In that range, the human eye uses rods to sense light. Since the rods have a single absorption maximum *scotopic* efficacy of about 1700 lumens/W at a wavelength of 507 nm according to the definition of the CIE 1951 scotopic standard observer[167], scotopic vision is colour blind. The sensitivity range of the rods makes the eye more sensitive to blue light at night, while red light is almost exclusively perceived through photopic vision.

[167] https://en.wikipedia.org/wiki/Luminosity_function
[168] Schelle (2014): 'Maximum Efficacy/Efficiency of Coloured Light and Practical Applications', By Donald Schelle, Analog Field Applications Engineer - Texas Instruments Article Q1/CY14, February 17, 2014, www.ti.com

Mesopic vision is the scientific term for a combination between photopic vision and scotopic vision in low (but not quite dark) lighting situations.
The combination of the higher total sensitivity of the rods in the eye for the blue range with the colour perception through the cones results in a very strong appearance of bluish colours (e.g. flowers) around dawn.

Please note that the assessment of the advantages/disadvantages of more white light in road lighting is complicated and the subject of ongoing research studies (e.g. EU Growth Project 'MOVE: Mesopic Optimisation of Visual Efficiency') coordinated by the CIE Technical Committee on 'Visual Performance in the Mesopic Range' (1-58)). As a consequence, at low light levels or so called 'mesopic view conditions' photometric values such as lamp efficacy or luminance could be corrected.

Temperature:
See section 3.2.2.
Line voltage:
See section 3.2.2.
Lamp voltage:
See section 3.2.2.
Power factor compensating capacitor aging:
See section 3.2.2.
Weather conditions:
TBW.
Traffic density:
TBW. (Input required: might be related to EN 13201-1?)
Car headlights:
It is also possible to provide road lighting with car headlights for motorized traffic, but so far EN 13201 does not take this into account. In Task 4 it is possible that the impact from car headlights will be discussed.

**Conclusions and values used for this study:**
It is proposed to neglect in this study the losses due to deviations in operating conditions of luminaires and light colour from the standard conditions, as discussed, because more precise data and evidence is missing and also taking these effects into account is not a common practice.
Nevertheless, it is worthwhile assessing (if possible) the potential impact of new types of smart car headlights in road class M, e.g. high beam headlights to reduce glare for counter-flow traffic.

## 3.3 Indirect impact of the use phase on energy consumption

**Scope:** The objective of this section is to identify, retrieve and analyse data, and report on the environmental & resources impacts during the use phase for ErP with an in*direct* energy consumption effect. This is only relevant for indoor lighting.

### 3.3.1 Heat replacement effect in buildings

TBW (An example/reference building with full EN 15193 calculation and a monthly energy balance would be welcome).
Note: this will depend on the heating/cooling period of the selected building.

### 3.3.2 Impact on the cooling loads in buildings

TBW(An example/reference building with full EN 15193 calculation and a monthly energy balance would be welcome).
Note: this will depend on the heating/cooling period of the selected building.

### 3.3.3 Conclusion on indirect impact on heating and cooling in buildings

TBW

## 3.4 End-of-Life behaviour

**Scope:** The scope of this section is to identify, retrieve and analyse data, and report on consumer behaviour (avg. EU) regarding end-of-life aspects. This includes: product use & stock life, repair- and maintenance practice and other impact parameters.

### 3.4.1 Economic Lifetime of the lighting installation

#### *3.4.1.1 Economic Lifetime of indoor lighting installations*

Because the lifetime of lighting equipment is shorter than of buildings, there is a natural need for recurring retrofits[169].
A measurement campaign in offices in the PACA region in France showed that the average age of a luminaire for fluorescent tubes is 10.1 years [151],[152].
The SAVE study[170] reports an average life of a lighting installation in offices in the EU-15 of 24 years: ranging from 19 years in the West region (reported by UK and Ireland) to up 28-30 years in the North region (reported by Finland and Denmark respectively).

*Experience in the Netherlands shows that in half of the offices a lighting system of over 20 years is installed*. These miss out on the technological developments and the related savings. Philips states that office lighting is often out-of-date because the rate of replacement is very, very slow. Per office, yearly 7 to 10% of the lighting is replaced; so it takes about 15 years before a lighting installation is replaced (Berno Ram in Van de Wiel, H., 2006). In another report[171] this concern was also confirmed. The average lighting stock gradually improves as newer, more efficient installations replace old, inefficient ones; however, much of the existing stock remains unchanged. The governments of the New Member States report the highest level of need for refurbishment in the EU.

The data presented above are also consistent with the information retrieved from the expert inquiry in the lot 8 study (2007): in Belgium, Germany and Spain lighting installations are currently being renewed in offices on average every 15-20 years. The German respondent remarked that a partial renovation, refurbishment or repair will be more frequent, but a total reinstallation less so.

**Conclusion:**
The lighting installation lifetime is assumed to be 20 years on average (+/- 10 years)

#### *3.4.1.2 Economic Lifetime of road lighting installations*

The average overall lifetime for luminaires is expressed in years after placement. Because the lifetime is only influenced by local conditions such as weather (humidity, wind…), pollution, vibrations caused by traffic density, etc., time in service should not be taken into account. A lifetime of 30 years is common practice. This figure is based on practical experiences and is confirmed by the first responses to our inquiry (Table 3-9). The variation can be considerable. Whereas in the centre of municipalities and in shopping streets - where public lighting is an element of street furniture - replacement times can be much shorter e.g. 15 years. In rural areas - with very low traffic density - luminaires with an age of 35 years and even more can be encountered. Many

[169] ATLAS, 2006. http://ec.europa.eu/comm/energy_transport/atlas/htmlu/lightdmarbarr.html
[170] Novem, 1999. Study on European Green Light: Saving potential and best practices in lighting applications and voluntary programmes. SAVE report
[171] Ecofys, 2005. Cost-effective climate protection in the building stock of the new EU Member States: Beyond the EU Energy Performance of Buildings Directive. Report for EURIMA

installations of 20 years and older are of course no longer complying with the standards on illumination, depending on the maintenance regime applied. Regular cleaning of the luminaire is necessary. This cleaning necessity depends strongly on the characteristics of the luminaire. Where the reflector of an open luminaire needs a new polish and anodizing at least every 10 years; a cleaning of the outer glazing at lamp replacement can be sufficient for luminaires with an IP65 optical compartment.
As mentioned before, a product life of 30 years for a luminaire is common practice, but the standard deviation on this lifetime is significant. In the centre of municipalities and in shopping streets, public lighting installations are an element of street furniture and therefore often have shorter replacement times.

**Conclusion:**
Regarding average installation lifetime, see Table 3-9.

*Table 3-9: Luminaire life time: parameter values applied in this study*

| | Road class M | | | Road class C | | | Road class P | | |
|---|---|---|---|---|---|---|---|---|---|
| | min. | avg. | max | min. | avg. | max | min. | avg. | max |
| life time (y) | 25 | 30 | 35 | 25 | 30 | 35 | 15 | 30 | 35 |

### 3.4.2 Typical maintenance time for indoor lighting systems

Maintenance costs may have a major impact on equipment choices: for long time uses, one may prefer long life duration light sources to minimise employment-related refurbishing costs. Lack of understanding of the consequences of poor maintenance leads to many lighting installations being poorly maintained. There are indications that the benefits of maintenance are not clearly understood by lighting owners[169].
The required installation and maintenance time, estimates are included in Table 37 on the basis of experience.

*Table 3-10: Estimation of maintenance and installation cost related parameters used for LCC calculations in this study*

| | |
|---|---|
| Time required for installing one luminaire (t-luminaire install) | 20 min. |
| Time required for group lamp replacement (t-group relamping) | 3 min. |
| Time required for spot lamp replacement (t-spot relamping) | 20 min. |
| Time required for luminaire cleaning (in addition to time for group lamp replacement) (t-luminaire cleaning) | 1.5 min. |

### 3.4.3 Typical maintenance time of road lighting systems

The required installation and maintenance time for street lighting was estimated based on 25 years of experience in Belgium (L. Vanhooydonck) and is included in Table 3-11.

*Table 3-11: Estimation of maintenance and installation time parameters*

| | |
|---|---|
| Time required for installing one luminaire (group installation) | 20 min. |
| Time required for lamp replacement (group replacement) | 10 min. |
| Time required for lamp replacement (spot replacement) | 20 min. |
| Time required for maintenance including ballast replacement | 30 min. |

### 3.4.4 Frequency of maintenance cycle and repair or re-lamping of installations

*In non-residential lighting it is common practice to compare solutions based on the total system costs[172],[173] taking into account the capital cost related to the initial installation, with the estimated energy cost and cost for maintenance. Of course, this does not exclude that many existing installations are operating on the market that do not follow their planned maintenance schedule.*

**Approach:**

The typical periods for maintenance on installations are:

**tgroup =** is the time for group lamp replacement in years (y)

**tcleaning =** is the period for cleaning luminaires and lamps

**tspot =** is the period for a spot replacement of a lamp or an abrupt failure of an LED luminaire.

The time period for a group replacement (tgroup) defines the Lamp Survival Factor (FLS) or in case of LEDs by the LED module failure fraction, Fy (IEC 62717). They are related to manufacturing data, see Task 4 on technology.

The time period related to cleaning (tcleaning) is related to cleaning luminaires and the Luminaire Maintenance Factor (FLM), see sections 3.2.1.3 and 3.2.3.3. Group replacement and luminaire cleaning can be combined, for example tgroup = 2xtcleaning.

The annual consumption of lamps per luminaire in standard conditions is straightforward and related to the Lamp Survival Factor (FLS) and the time period for group replacement ($t_{group}$) in years:

$$N_y = 1 / t_{group} + (1 - F_{LS}) / t_{group}$$

Note: it is assumed that when carrying out spot replacement only the broken lamp is replaced even when several lamps are installed in one luminaire.

The annual consumption of ballasts (electronic control gear) per luminaire in standard conditions (ballast tc point @ 70 °C) will be modelled according to catalogue data (OSRAM catalogue 2006/2007 p. 11.132):

$$Nb = BFR/100 \times t_{operating} / 1000h \times Nbal$$

Where:

- BFR = ballast failure rate per 1000 h with the ballast tc point @ 70 °C.
- Nbal = number of ballasts per luminaire.



[172] licht.wissen 01 'Lighting with Artificial Light' available from licht.de

[173] ZVEI(2013): 'Guide to Reliable Planning with LED Lighting Terminology, Definitions and Measurement Methods: Bases for Comparison'.

In this study a BFR of 0.2 % will be used for electronic ballasts (OSRAM catalogue 2006/2007 p. 11.132) and 0 % for magnetic ballasts. The same approach can be used for LED control gear.

Abrupt failure of LED luminaires can is defined as LED luminaire catastrophic failure rate, Cz (IEC 62717). The light degradation of LED luminaires is indicated in this standard by rated life Lx, where luminous flux declines to a percentage x of initial luminous flux. Typical values of 'x' are 70 (L70) or 80 percent (L80) for a given rated or useful life (e.g. 20000 h). The percentage of LED luminaires that have a catastrophic failure or failed completely by the end of rated life 'Lx' (e.g. L80) is expressed by 'Cz'. For example C10 means 10 % catastrophic failures at rated life (e.g. 16000 h) with L80.
In this study it will be assumed that FLS = Cz for LED luminaires, for example C10 results in $F_{LS}$ = 0,10.

**Background:**
More information on the maintenance factor and frequency of luminaire cleaning can be found in section 3.2.1.3.

The ballast lifetime depends on service hours. Normally, magnetic ballasts last as long as the luminaires if they are placed inside the luminaire (and thus are protected against rain). For electronic ballasts, lifetimes of 40,000 to 60,000 hours (10 to 15 years) are considered as realistic by the manufacturers. The lifetime of electronic ballasts or control gear decreases strongly if the working temperature exceeds the indicated working temperature in reality.
The lifetime of ignitors associated with magnetic ballasts does not depend on hours in service but on the number of times that the lamps are switched on. Experience shows that the lifetime of an ignitor can match the lifetime of a luminaire with an acceptable survival rate. An electronic ballast includes an ignition device and does not have a separate ignitor.
With electromagnetic gear, in addition to a ballast and ignitor, a capacitor has to be used to improve the power factor (cos φ) of the lighting installation. An unsatisfactory power factor causes higher currents and by consequence higher cable losses. The quality of a capacitor and thus the amelioration of the power factor decreases over service time. The maximum useful lifetime declared by capacitor manufacturers is 10 years.
An electronic gear is designed to have a power factor of at least 0.97 and has no additional capacitor.
For most lamps lumen maintenance, burning hours and failure rate are interrelated as illustrated in Table 3-12.

*Table 3-12: $F_{LLM}$ and $F_{LS}$ data for selected lamps*

| Burning hours | | 10000 h | 15000 h | 20000 h |
|---|---|---|---|---|
| FL triphosphor on magn. ballast | FLLM | 0.9 | 0.9 | |
| | FLS | 0.98 | 0.5 | |
| FL triphosphor on electronic ballast (preheat) | FLLM | 0.9 | 0.9 | 0.9 |
| | FLS | 0.98 | 0.94 | 0.5 |
| FL halo phosphate on magn. ballast | FLLM | 0.79 | 0.75 | |
| | FLS | 0.82 | 0.5 | |
| CFLni on magn. ballast | FLLM | 0.85 | | |
| | FLS | 0.5 | | |
| CFLni on electronic ballast (preheat) | FLLM | 0,9 | 0,85 | |
| | FLS | 0,95 | 0,5 | |

**Conclusions and data used for this study:**

TBW

### 3.4.5 Recycling and disposal of the luminaire

Recycling and disposal of the luminaire, ballast, lamps and other electronic parts is the responsibility of the manufacturers according to the WEEE Directive. Manufacturers can choose between organizing the collection themselves or join a collective initiative such as Recupel (Belgium), RecOlight (U.K.), Recylum (France), Ecolamp (Italy),…. These organizations provide the collection and recycling service for the manufacturers and collect the waste from installers or companies doing technical maintenance & repair in street lighting. In practice, installers or companies doing technical maintenance & repair, remove and collect the luminaires and separate the lamps.
Additional information is given at: www.recupel.be, www.ear-project.de, www.zvei.org, www.uba.de, www.bmu.de, www.altgeraete.org, www.bitkom.org, www.Eco-Lamp.sk, www.dti.gov.uk.
With respect to hazardous substances in the other parts, PCB's can still be found in old capacitors within equipment that is older than approximately 20yrs. The use of PCBs in new equipment is forbidden and in practice is no longer the case.

See also the light source study[148].

## 3.5 Local Infra-structure

**Scope:** The objective of this section is to identify, retrieve and analyse data, and report on barriers and opportunities relating to the local infra-structure regarding energy water, telecom, installation, physical environment...

### 3.5.1 Opportunities for lighting system design and the follow up process

As will be illustrated in Task 4 much of the energy saving possibilities created at system level are the results of starting with a good lighting system design. This is the job of the *lighting system designer* who brings together requirements of the visual tasks, requirements of people, opportunities provided by the space for example possibilities to ease or simplify installation and maintenance, availability of daylight, occupancy patterns, surface finishes, etc. By combining the correct luminaires with the best control strategy to match the space and tasks, and by providing flexibility in the lighting scheme to allow the lighting to be varied according to user requirements over time, energy savings may be made whilst providing a safe and comfortable environment. For this design process, the lighting designer can rely on existing EN standards such as EN 15193 or EN 13201-5 to optimise energy savings, see sections 3.2.1.1 and 3.2.3.1. In this design process minimum lighting performance requirements can be sourced from established standards such as EN 12464-1 for indoor lighting of work places, see also Task 1. This process using standards is also illustrated in Figure 1-2 and Figure 1-3. These standards can provide an objective basis for comparison of alternative designs and therefore yield to more optimised solutions.
After the design stage it is important that the installation complies with the design which is the job of *the installer*. Nevertheless, during the installation modifications could occur compared to the original design specification. For example, another carpet with a different reflection coefficient might be selected. This will have an impact on the performance, see section 3.2.1.4. Therefore it is useful to involve a *commissioning engineer*, who can incorporate these changes in the final lighting system settings to

obtain optimal performance. This will allow a *verification engineer* to check for final acceptance of the delivered system on behalf of the building owner.
Once the system has been delivered and starts operation, further savings can be obtained by an appropriate follow up of the lighting system. This can be done by *building operation and maintenance personnel*. For example as explained in later section 3.5.10, the task area function might change over the life time of the building which could require new lighting system settings. Also fine tuning of the building automation control system for occupancy and light measurement might be useful[111]. Luminaire cleaning can also contribute to energy savings, see sections 3.2.1.3 and 3.2.3.3.
As a conclusion, the full chain of potential actors that are ideally involved in the process from lighting design until operation and maintenance is illustrated in Figure 3-14. Using this full chain of actors could be an opportunity to increase employment while also having the economic benefits from the energy savings.

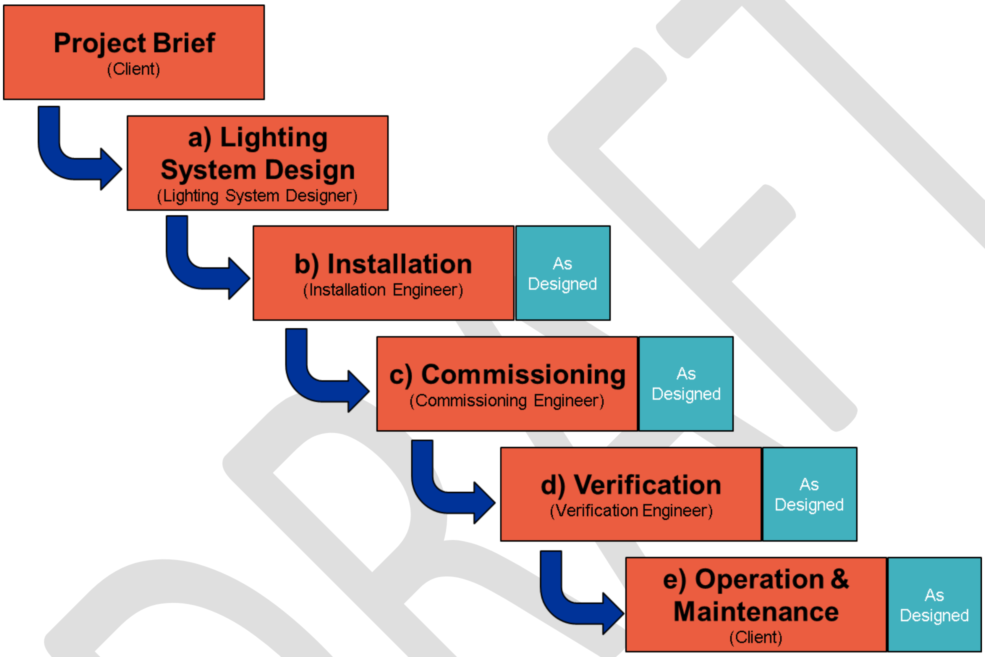


*Figure 3-14 Full chain of actors involved from lighting system design until maintenance and operation*

### 3.5.2 'Lock-in effect' for new products due to limitations imposed by existing in road lighting

Previous investments in infrastructure (lamp poles, grids) can obviously lead to 'lock in' effects. Usually, pole distances cannot be changed without substantial infrastructural changes and related costs. As a consequence the maximum obtainable energy savings cannot always be realized without additional investments.

*Figure 3-15: Street lighting luminaire attached to cables(left) and to electricity distribution (right)*

*Figure 3-16: Street lighting luminaires attached to poles(left) and to a house (right)*

Examples:

- Luminaires can be attached to poles for electricity distribution, to poles for public lighting only, to houses, or on cables above a street (see Figure 3-15 and Figure 3-16). It is clear that light point locations cannot be changed without great infrastructural changes and related costs. Therefore in re-lighting projects (with more efficient luminaires and/or more efficient lamps) the pole distance usually cannot be changed. If the new installation supplies a useful luminous flux that is higher than necessary, the maximum energy savings will not be reached.
- Public lighting can be connected together with the residential electrical distribution grid or have a separate grid. A separate grid is sometimes required for tele-management systems.
- Lamps are only sold in a defined and limited power series (e.g. 50-70-100-150 Watt). This implies that in real circumstances an overpowering can occur to meet the minimum required light levels. Fine tuning of the maximum lamp power set point by using lamp power dimmable ballasts or installing line voltage regulators can adjust the light output to the required levels.

- HID lamp power is regulated by the integrated ballast in the luminaire. This means that when replacing a lamp with a more efficient one, there is no energy saving but only more light output from the lamp. The only solution for this is again via fine tuning of the maximum lamp power set point with dimmable ballasts or installing line voltage regulators.

### 3.5.3 Lack of interest by authorities

Public street lighting has to provide good visibility to users of outdoor public traffic areas during the hours of darkness to support traffic safety, traffic flow and public security. On the other hand, the public authorities are responsible for procurement and management of public lighting installations. If the public lighting installations provide the required visibility, investments in energy saving projects that do not give quick earnings are often not a priority.

Examples:

- There exist many compromising motivating factors that can prevail at the design stage of public lighting installations, including: budget and planning for investments in new street lighting (infrastructure), pay-back period for new investments, risk of quality related complaints from adoption of new technology, general resistance to change, etc.
- A new trend called 'city beautification' can also be identified. The main objective is to make city centres more attractive and install decorative street lighting luminaires with designs that fit with historical buildings or the city character. Aesthetics are the most important parameter in this case and these might compromise the eco-design characteristics of street luminaires. In many cases design architects are dominating projects and it will be important that these people are aware of environmental impacts (see also limitation in 3.3.4) and of the advantages of new eco-designed products.

### 3.5.4 Lack of interest by the office building owner

As stated in the definition, the 'building owner' can influence many types of subcontractor activities. A simple overview of 'metrics for defining success' related to the contractor or subcontractor is shown in Table 3-13. All actors will try to influence the 'building owner' and motivation can therefore be very diverse. Finally, the lighting designer (if involved) needs to look for a compromise solution and the products which best meet this. From the table it is also clear that there are many more factors involved then energy efficiency alone.

*Table 3-13: Compromising motivating factors that may influence the selection and design of lighting systems'*

| subcontractor/contractor | performance metric |
|---|---|
| Building developers* | euro per square meter |
| Electrical engineers* | Watt per square meter, code compliance |
| Lighting engineers* | illuminance, quality of light |
| Construction managers* | Planning and specifications/adherence to drawings |
| Contractors* | Budget and schedule (no call-backs) |
| Suppliers* | Sales and margins |
| Construction workers* | Signoff |
| Leasing agents* | Quick rental; euro per square meter |
| Building operators* | Simple payback |
| Maintenance staff* | Complaints |
| Architects** | Creative expression, Pride, Profit |
| Utility DSM (Demand Side Management) staff* | Euro per avoided kilowatt and kilowatt-hour |

* Adapted from Energy Efficient Buildings: Institutional Barriers and Opportunities by E-Source, Inc., 1992
** Adapted from Commercial and Industrial Lighting Study by Xenergy, Inc., 2000

### 3.5.5 Lack of knowledge or skilled subcontractors

The proliferation of more advanced lighting design and energy saving techniques can require additional skills that might  not be available thus can form a market barrier, see also section 3.5.1.
For example, freely available lighting design software lowers the technical barrier to lighting design without requiring basic knowledge regarding lighting fundamentals and awareness about realistic lighting system performance. As a consequence, there can sometimes be too much reliance on outputs of lighting software without scrutiny of the results.
Also complex lighting energy saving techniques where office, or building layout interacts (e.g. day lighting, presence detection, indirect lighting) could suffer from this lack of knowledge in the office design stage.

### 3.5.6 Lack of user acceptance for automatic control systems

It is important to take 'user acceptance' into account especially with automatic control systems. For example, experiences with complex daylight responsive control systems show that problems may occur when users do not know the purpose or how it works (IEA task 21 (2001)). These problems can vary from complaints to completely overruling the system through bypassing or deactivating it, which will normally leads to reduced energy saving.

### 3.5.7 Limitations imposed by local light colour preferences

It is possible that the local population, or the local authority purchasing the equipment, has preference for a certain light colour blend (gold, cold white, yellow, ..) that best fits their perception of comfort according to: local climate (warm, cool, rainy, snow,..), colour of street surrounding buildings, etc.

Examples:

- CIE defines a chromaticity diagram and provides a sense of the visual appearance of the light sources and an indication (colour temperature) of how visually a 'warm' or 'cool' lamp appears (1976 CIE chromaticity diagram).
- (IEA (2006)[174] p. 106): 'Lamp sales around the world reveals an apparent user preference for 'cooler' light sources the closer the illuminated locations is to the equator'.
- The high energy efficient High Pressure Sodium lamp have a warmer (gold) colour compared to the energy inefficient High Pressure Mercury lamp ('cool white').

### 3.5.8 Lack of skilled work force

The proliferation of more advanced lighting systems and energy saving techniques can require additional skills that people responsible for design and installation might be lacking, see also section 3.5.1.

Examples:

- This is especially the case for lighting energy saving techniques where complex tele-management technologies are used (e.g. traffic density and weather related dimming, fine tuning of maximum power point according to real street lighting surroundings, special lamp versus ballast requirements, etc.).
- Optical systems that require fine tuning related to the real surroundings.
- 'Easy to use' calculation programs, can give the impression that anybody can design street lighting installations. This fact may obscure a lack of design skills, discernment and scrutiny of the results.
- When urban architects are more involved in street lighting they need technical lighting designer skills.

### 3.5.9 Light pollution and sky glow

Much as artificial lighting provides a very useful service, it has also given rise to a side-effect known as 'light pollution'. For example, in most of our urban environments it is no longer possible to see any but the brightest stars as a consequence of light emitted by outdoor lighting illumination.
Light pollution is defined in guideline CIE 126(1997) on 'Guidelines for minimizing sky glow' as 'a generic term indicating the sum-total of all adverse effects of artificial light'. The next sections present a short summary of the adverse effects of artificial light that have been be identified in the literature.

Sky glow' (Figure 3-17) is defined (CIE 126(1997)) as:
'the brightening of the night sky that results from the reflection of radiation (visible and non-visible), scattered from constituents of the atmosphere (gas molecules, aerosols and particulate matter), in the direction of the observation. It comprises two separate components as follows:

(a) Natural sky glow – That part of the sky glow which is attributed to radiation from celestial sources and luminescent processes in the Earth's upper atmosphere.

(b) Man-made sky glow – That part of the sky glow which is attributable to man-made sources of radiation (e.g. outdoor electric lighting), including radiation that is emitted directly upwards and radiation that is reflected from the surfaces of the Earth'.

Potential obtrusive effects from outdoor lighting are described in technical guide CIE 150 (2003) on 'The limitation of the effects of obtrusive light from outdoor lighting installations'.

[174] IEA, 2006. Light's Labour's Lost: Policies for energy-efficient lighting'

'Obtrusive light' is defined (in CIE 150) as 'spill light, which because of quantitative, directional or spectral attributes in a given context, gives rise to annoyance, discomfort, distraction or a reduction in the ability to see essential information' (CIE 150 (2003)).

There are also adverse effects of outdoor lighting reported[175],[176],[177]on: the natural environment (e.g. insect, disruption of bird habitats, etc.), residents (e.g. light trespass in bedrooms), on transport system users (e.g. Figure 3-17), sightseeing and astronomical observation.
It is therefore also possible to distinguish 'astronomical light pollution' that obscures the view of the night sky, from 'ecological light pollution', that alters natural light regimes in terrestrial and aquatic ecosystems. 'The more subtle influences of artificial night lighting on the behaviour and community ecology of species are less well recognized, and could constitute a new focus for research in ecology and a pressing conservation challenge'[178].

*Figure 3-17: Examples of light pollution: sky glow (left) and glare (right)*

In the case of street lighting luminaires research shows that the emission angle of the upward light flux plays a role in reducing sky glow[179]. It was found that if the distance from the city increases, the effects of the emission at high angles above the horizontal decrease relatively to the effects of emission at lower angles above the horizontal. Outside, some kilometers from cities or towns, the light emitted by luminaires between the horizontal and 10 degrees above the horizontal is as important as the light emitted at all the other angles in producing the artificial sky luminance. Therefore to reduce the light emitted between the horizontal and 10 degrees above by street lighting luminaires could be an objective in fighting light pollution.

It is expected that measures aiming at increasing energy efficiency will reduce the amount of wasted light and have a positive effect on mitigating "light pollution".

[175] CIE 150 (2003) technical report.
[176] Narisada K. & Schreuder D. (2004) Light pollution handbook., Springer verlag 2004, ISBN 1-4020-2665-X
[177] Steck B. (1997) Zur Einwirkung von Aussenbeleuchtungsanlagen auf nachtaktive Insekten', LiTG-Publikation Nr. 15, ISBN 3-927787-15-9
[178] T. Longscore & C. Rich (2004): 'Ecological light pollution', Frontiers in Ecology and the Environment: Vol. 2, No. 4, pp. 191–198
[179] Cinzano et al. (2000a) ' The Artificial Sky Luminance And The Emission Angles Of The Upward Light Flux', P. Cinzano, F.J. Diaz Castro, Mem. Soc. Astro. It., vol.71, pp. 251-256

### 3.5.10 Selection of the task area according to EN 12464 and impact on the light levels

It is important that the designer does not over specify the requirements of each area in the building, for example in Table 3-1 on general areas such as gangways in buildings. Apart from that it is also important to clearly define task areas because the illuminance of the immediate surrounding area may be lower than the illuminance on the task area but shall be not less than the values given in Table 3-15.

*Table 3-14 Relationship of illuminances on immediate surrounding to the illuminance on the task area*

| Illuminance on the task area $E_{task}$ lx | Illuminance on immediate surrounding areas lx |
|---|---|
| ≥ 750 | 500 |
| 500 | 300 |
| 300 | 200 |
| 200 | 150 |
| 150 | $E_{task}$ |
| 100 | $E_{task}$ |
| ≤ 50 | $E_{task}$ |

*Table 3-15 General areas inside buildings – Storage rack areas*

| Ref. no. | Type of area, task or activity | $\bar{E}_m$ lx | $UGR_L$ – | $U_o$ – | $R_a$ – | Specific requirements |
|---|---|---|---|---|---|---|
| 5.5.1 | Gangways: unmanned | 20 | - | 0,40 | 40 | Illuminance at floor level. |
| 5.5.2 | Gangways: manned | 150 | 22 | 0,40 | 60 | Illuminance at floor level. |
| 5.5.3 | Control stations | 150 | 22 | 0,60 | 80 | |
| 5.5.4 | Storage rack face | 200 | - | 0,40 | 60 | Vertical illuminance, portable lighting may be used. |

### 3.5.11 Selection of the road classes according to EN 13201 and impact on light levels

It is important that the designer does not over specify the requirements of the road classes in EN 13201-2 because they can significantly impact energy consumption, see for example M classes in Table 3-16 . As mentioned EN 13201-1 serves as a guideline for selecting these classes but each EU country has converted this differently into their national standards.

*Table 3-16 Example of EN 13201-2 road classes lighting requirements*

**Table 1 — M lighting classes**

| Class | Luminance of the road surface of the carriageway for the dry and wet road surface condition | | | | Disability glare | Lighting of surroundings |
|---|---|---|---|---|---|---|
| | Dry condition | | | Wet | Dry condition | |
| | $\overline{L}$ in cd/m² [minimum maintained] | $U_0$ [minimum] | $U_l$ [a] [minimum] | $U_{0w}$ [b] [minimum] | $f_{TI}$ in % [c] [maximum] | $R_{EI}$ [d] [minimum] |
| M1 | 2,00 | 0,40 | 0,70 | 0,15 | 10 | 0,35 |
| M2 | 1,50 | 0,40 | 0,70 | 0,15 | 10 | 0,35 |
| M3 | 1,00 | 0,40 | 0,60 | 0,15 | 15 | 0,30 |
| M4 | 0,75 | 0,40 | 0,60 | 0,15 | 15 | 0,30 |
| M5 | 0,50 | 0,35 | 0,40 | 0,15 | 15 | 0,30 |
| M6 | 0,30 | 0,35 | 0,40 | 0,15 | 20 | 0,30 |

### 3.5.12 Indoor light installed for non visual aspects of lighting contributing to energy consumption

Visible light sources can also be installed in for non-visual aspects, for example with the aim to influence sleep/wake cycles, alertness, performance patterns, core body temperature or production of hormones. Such effects are described in the German Standard DIN 5031-10:2013-12 on 'Optical radiation physics and illuminating engineering - Part 10: Photobiologically effective radiation, quantities, symbols and action spectra'. Clearly, this application can contribute to additional energy consumption of light sources in buildings but they do not belong to the application of Standard EN 12464-1 on indoor lighting in work places and therefore to the proposed scope of this study.

## 3.6 Recommendations

### 3.6.1 Refined product scope

To be done on the final version

### 3.6.2 Barriers and opportunities

To be done on the final version

# CHAPTER 4 Technologies (product supply side, includes both BAT and BNAT)

**The Objective**

This chapter addresses the MEErP Task 4, in which the objective is to analyse technical aspects related to lighting systems. Typical products and systems on the market and alternative design options are described, including indications of the use of materials, performance and costs. Additionally, information on product manufacturing, distribution, durability and end-of-life processing is reported. Best Available Technologies (BAT) and Best Not yet Available technologies (BNAT) are also analysed, in which:

- 'Best' shall mean most effective in achieving a high level of environmental performance of the product.
- 'Available' technology shall mean that it is developed on a scale which allows implementation for the relevant product under economically and technically viable conditions, taking into consideration the costs and benefits, whether or not the technology is used or produced inside the Member States in question or the EU-28, as long as they are reasonably accessible to the product manufacturer. Barriers for take-up of BAT should be assessed, such as cost factors or availability outside Europe.
- 'Not yet' available technology shall mean that it is not yet developed on a scale which allows implementation for the relevant product but that it is subject of research and development. Barriers for BNAT should be assessed, such as cost factors or research and development outside Europe.

The full details of the MEErP content for this task are summarised in Annex A.

**Summary of task 4:**

This is a draft version made in a preparatory phase of the study to collect data from stakeholders. A summary of this task will be elaborated during the completion of the draft final report. This version is released with a complementary calculation spreadsheet that models technological and economical improvement options at system level (available on request for stakeholders who want to contribute). The purpose of this version is to check with stakeholders the approach and how data can be provided to complete the document. From the draft results it is already clear that, apart from improving the lamp efficacy, many other improvement options at system level can contribute to more energy savings. The calculated outcomes for the a cellular office with ceiling mounted luminaires resulted in a Lighting Energy Numerical Indicator (LENI) as defined in EN 15193 for the Worst Case design of 52.7 kWh/m²y, for the mainstream 26 kWh/m²y and for the best of BAT it was only 5.7 kWh/m²y. It is also clear that such a high improvement potential is not only due to an increase of the light source efficacy that was assumed to increase from 75 lm/W up to an expected 140 lm/W for LED luminaires. Similar results were obtained for outdoor lighting that were calculated in line with the standard prEN 13201-5 and which is currently under development. Improvement is a combination of many design options and parameters.

Comment: This report is currently a work in progress, as some parts of the study have not yet received the benefit of comments and data from stakeholders, therefore it should not be viewed as a final report.

## 4.1 Technical product description of lighting systems

**Objective and general approach:**

This section follows the decomposition into components and/or subsystems of the lighting system that has been introduced in Task 1 in Figures 1-1, 1-2 and 1-3. For the further reading of this task report it is important to understand this decomposition and all its defined parameters. Of equal importance is being aware that the proposed scope in Task 1 was to focus on lighting systems installed where minimum requirements are valid according to the standard series EN 12464 (indoor lighting) and EN 13201 (outdoor lighting) and that these standards use the concept of minimum 'maintained illuminance or luminance'. By consequence, initial installations are over-dimensioned compared to the minimum required and that the maintenance factors as defined in Task 1 are taken into account based on the current user practices and maintenance schemes that are explained in Task 3 on Users.

Because there are many parameters involved in optimising lighting systems(see Figures 1-2, 1-3), this results in many different possible variations and it is a challenge to discuss systematically all these improvement lighting design options. Moreover, it is also important to do this on an equal basis for comparison. Therefore in the subsequent sections the improvement design options will be grouped into categories (worst case, mainstream, ..) for the set of selected reference lighting applications in Task 3 and analysed at subsystem level as previously defined in Task 1. Data is processed in a spreadsheet complementary to this report, this spreadsheet is available on request for stakeholders who want to contribute with data in Task 4. The spreadsheet also enables to simulate many other options that are not discussed in detail or not yet included in this draft version. Each application has its own sheet and every design solution is a column. The main purpose is to assess the impact of the individual improvements at component and/or subsystem level on the overall energy performance of the selected reference lighting systems.

In brief the reference lighting applications proposed in Task 3 were:

- Cellular office with ceiling mounted luminaires (cellular ceiling mounted)
- Cellular office with suspended luminaires (cellular suspended)
- Open plan office with ceiling mounted luminaires (open ceiling mounted)
- Open plan office with suspended luminaires (open suspended)
- Motorized road with fast traffic class M3 (EN 13201)
- Conflict road with mixed traffic class C3 (EN 13201)
- Pedestrian area road with slow traffic class P3 (EN 13201)

For these reference lighting systems we will look at 'a Worst Case', 'a Mainstream design', 'several BAT designs' and 'BNAT designs' on energy use or other environmental improvements. Also indoor and outdoor lighting will be discussed in separate sections because of the strong differences in standards and user requirements. Note: in the final version also other types of reference designs might be added for modelling, for example in line with policy scenarios of the lot 7 light source study[180].

In the Best Available Technology(BAT) sections, several options at the installation level will be considered apart from each other and discussed in detail because they were not subject of the eco-design light source study[180]. For light sources and control gear the BAT from this study[180] will be assumed without repeating the details and their background.

In a final concluding section all data will be grouped and compared on energy use.

[180] http://ecodesign-lightsources.eu/

Note: this is a first draft concept version for discussion with stakeholders on how and which data is useful and can be provided, in a later version more documentation will be added.

### 4.1.1 Worst case (WC) or high energy using lighting indoor systems

**Approach:** This section on Worst Case or high energy using systems assesses the lowest energy performance products that can enter the market (2016). They could also be used in later sections for modelling the stock of existing systems, to be considered if another category needs to be introduced for this in the event that this is deemed relevant and that data is available.

#### *4.1.1.1 The WC control system level indoor*

The WC control system following the definitions of EN 15193 is:

constant illumination control(EN 15193): none
occupancy control type(EN 15193): Manual On/Off
room type absence (EN 15193): Open>sense 30m² (open plan office), Cellular 2-6 p. (cellular office)
type of daylight control (Table F.16) (EN 15193): Manual
type of blinds control (annex F 3.2.4) (EN 15193): Manual operated blinds

The expected impact on product price:

No additional costs

Examples and rationale for selected data:

The proposed selection is the least performing solution in EN 15193. It is based on manual operated light switches and operated louvres.
Basic light switches and solar blinds are part of the building infrastructure, therefore no extra costs for this solution will be taken into account.

#### *4.1.1.2 WC control gear or ballast indoor*

The proposed worst case Power efficiency of the Luminaire is:

$\eta p$ = 0.762 or 76.2 %
no dimming
Pc (luminaire control stand by power)(W): 0 W

The expected impact on product price of this solution is:

It is normally included in a basic luminaire, therefore for this solution no extra costs compared to the luminaire will be taken into account.

Examples and rationale for the selected data:

This value was taken according to Regulation 245/2009 for a typical T8-18Watt lamp class A3 ballast: $\eta p$ = 76.2 %

#### *4.1.1.3 WC luminaire and lamp efficacy indoor*

The proposed worst case luminaire performance parameters are (see Task 1 for definitions):

$\eta ls$ = 75 lm/W
FLLM @ 8000 h = 0.90
FLS @ 8000 h = 0.90
Cellular suspended: RLO = 0.74
CIE flux code: 0.75/0.99/0.99/0.92/0.74/0.75/1.00/1.00/0.08
Cellular ceiling mounted: RLO = 0.47
CIE flux code: 0.47/0.79/0.96/1.00/0.47
Open plan suspended: RLO = 0.73

CIE flux code: 0.75/0.99/0.99/0.92/0.74/0.75/1.00/1.00/0.08
Open plan ceiling mounted: RLO = 0.47
CIE flux code: 0.47/0.79/0.96/1.00/0.47
Suspended: FLM = 0.92
Ceiling mounted: FLM = 0.91

The expected luminaire price for this solution is:
Suspended: 100 euro (excl. VAT) (3 x 18 W LFL)
Ceiling mounted: 70 euro (excl. VAT) (1 x 28 W LFL)
(these worst case designs are not optimized and therefore will not take into account additional cost for lighting design)

Examples and rationale for the selected data:
The worst case RLO values used for luminaire efficiency are sourced from the lot 8 office lighting study.
The lamp efficacy(ηls) is according to Regulation 245/2009 stage 3 for a LFL T8-18Watt lamp.
The luminaire maintenance factor (FLM) was sourced from standard CIE 97 (2005) for a Class B open top housing luminaire in the case of a ceiling mounted luminaire and Class C closed top housing for a ceiling mounted luminaire both in a very clean environment and an elapsed time between cleaning of two years.
The price is the lowest price that was found on an online retailer website[181] for a similar luminaire.

#### *4.1.1.4 WC Installation indoor*

The proposed worst case installation parameters are (see Task 1 for definitions):
Cellular suspended: EN 13032 calculated with flux code = TBD
Cellular ceiling mounted: EN 13032 calculated with flux code = TBD
Open plan suspended: EN 13032 calculated with flux code = TBD
Open plan ceiling mounted: EN 13032 calculated with flux code = TBD
FRSM = 0.96
Reflectance ceiling/wall/floor: 0.7/0.5/0.2 (see Task 3)
FCL in cellular office = 1 + (1-6/4)/2 = 1.25
FCL in open plan office = 1

Note: the respective reference geometries have been defined in Task 3.

The expected installation price for this solution is:
For installation times and associated cost per luminaire see Task 3.

Approach for design cost:
Included with the luminaire.

Examples and rationale for the selected data:
The Utilance is calculated with the flux code.
The room surface maintenance factor was sourced CIE 97(2005) for a very clean working environment with cleaning of walls and ceiling every year.
The Factor for over-dimensioning FCL is assumed to be in between selecting for 4 or 6 luminaires in a cellular office. In an open plan office this effect is assumed to be neglectable because of the high amount of luminaires.

[181] www.voltus.de

### 4.1.2 Mainstream or medium energy using lighting indoor systems

**Approach:** This section on mainstream or medium energy use systems considers average systems found on the market today reflected by the selected reference designs (see Task 3). They could also be used in later sections for modelling the stock of existing systems, to be considered if another category needs to be introduced for this in the event that this is deemed relevant and that data is available.

#### *4.1.2.1 The MAINSTREAM control system level indoor*

The same assumptions as for the worst case system will be used, as we will assume that automated controls are not generally applied.

#### *4.1.2.2 MAINSTREAM control gear or ballast indoor*

The proposed mainstream Power efficiency of the Luminaire is:

ηp = 0.842 or 84.2 %
no dimming
Pc (luminaire control stand by power)(W): 0 W

The expected impact on product price of this solution is:

It is little more expensive compared to the worst case ballast: assumption + 5 euro (TBC).

Examples and rationale for the selected data:

This value was taken according to Regulation 245/2009 for a typical T8-18 Watt lamp class A2 ballast: ηp = 84.2 %

#### *4.1.2.3 MAINSTREAM luminaire and lamp efficacy indoor*

The proposed mainstream luminaire performance parameters are (see Task 1 for definitions):

ηls = 86 lm/W
FLLM @ 16000 h = 0.90
FLS @ 16000 h = 0.90

Cellular suspended: RLO = 0.85
CIE flux code: 0.67/0.94/0.98/0.36/0.85/0.75/1.00/1.00/0.64
Cellular ceiling mounted: RLO = 0.68
CIE flux code: 0.64/0.92/0.98/1.00/0.68
Open plan suspended: RLO = 0.85
CIE flux code: 0.67/0.94/0.98/0.36/0.85/0.75/1.00/1.00/0.64
Open plan ceiling mounted: RLO = 0.68
CIE flux code: 0.64/0.92/0.98/1.00/0.68

Suspended: FLM = 0.92
Ceiling mounted: FLM = 0.91

The expected luminaire price for this solution is:

Suspended: 200 euro (excl. VAT) (e.g. 2x36 W LFL)
Ceiling mounted: 200 euro (excl. VAT) (e.g. 2x36 W LFL)
(The higher price of this mainstream product can be justified because in this case we assume that a photometric file is available and that design services are included)

Examples and rationale for the selected data:

The mainstream RLO values used for luminaire efficiency and flux code are the average from the lot 8 office lighting study.
The lamp efficacy (ηls), FLLM, FLS are according to Regulation 245/2009 stage 3 for a LFL T5-14Watt lamp.

The luminaire maintenance factor ($F_{LM}$) was sourced from standard CIE 97 (2005) for a Class B open top housing luminaire in the case of a ceiling mounted luminaire and Class C closed top housing for a ceiling mounted luminaire both in a very clean environment and an elapsed time between cleaning of two years.
The price is used is the average price from the lot 8 and cross checked with online retailers[182], [183] for a similar luminaire.

#### 4.1.2.4 MAINSTREAM Installation indoor

The proposed mainstream installation parameters are (see Task 1 for definitions):

Cellular suspended: U = EN 13032 calculated with flux code = TBD
Cellular ceiling mounted: U = EN 13032 calculated with flux code = TBD
Open plan suspended: U = EN 13032 calculated with flux code = TBD
Open plan ceiling mounted: U = EN 13032 calculated with flux code = TBD
$F_{RSM}$ = 0.96
Reflectance ceiling/wall/floor: 0.7/0.5/0.2 (see Task 3)
$F_{CL}$ in cellular office = 1.25
$F_{CL}$ in open plan office = 1

Note: the respective reference geometries have been defined in Task 3.

The expected installation price for this solution is:
For installation times and associated cost per luminaire see Task 3.

Approach for design cost:
Included with the luminaire (see previous section).

Examples and rationale for the selected data:
The Utilance is calculated with the flux code.
Other parameters are sourced from the WC, because they are assumed as mainstream.

### 4.1.3 BAT or low energy using lighting indoor systems

**Approach:** This section on BAT or low energy use systems considers the best systems found on the market today. BATref is a reference BAT system with no specific installation level improvement options implemented apart from automation as modelled in EN15193, but other BAT options can be defined. They could also be used in later sections for modelling the impact of any future policy measures, to be considered if another category needs to be introduced for this in the event that this is deemed relevant and that data is available.

#### 4.1.3.1 The BATref control system level indoor

Dimmable control gear with:
Pc (luminaire control stand by power)(W): to be defined W

The BAT control system following the definitions of EN 15193 is:
constant illumination control(EN 15193): yes
occupancy control type(EN 15193): presence detector
room type absence (EN 15193): Open>sense 10m² (open plan office), Cellular 2-6 p. (cellular office)
type of daylight control (Table F.16) (EN 15193): No stand-by losses, no switch-on, dimmed. EN 15193 defines this mode as 'Systems which are daylight-

[182] www.voltus.de
[183] http://www.eibmarkt.com/

responsive, and dim the electric lighting: The electric lighting is switched off and turned on again ("dimmed, no stand-by losses, switch-on"). The electric lighting is dimmed to the lowest level during usage periods (periods with adequate daylight) and switched off (i.e. no electrical power is used). The electric lighting system is turned on again automatically.' Note, switching devices such as bistable or latching relays[184] should be used in this operation mode.
type of blinds control (annex F 3.2.4) (EN 15193): Automatic operated blinds

The expected impact on product price:
Stakeholders are invited to provide input

Examples and rationale for selected data:
The proposed selection is the best performing solution described in EN 15193. It is based on presence detectors, daylight responsive sensors and automatic operated louvres.
Notes:

- Louvres are considered to belong to the so-called system environment of the lighting system, because they are normally installed to reduce glare and moreover they reduce the amount of available daylight. Therefore they are in a strict sense not part of the lighting installation itself but are part of the system environment as discussed in Task 1.
- Special systems such as light guides[185] or others sensors can be discussed in a separate section. Light guides, as opposed to louvres, will contribute to more daylight and could therefore be seen as part of the lighting system.

Stakeholders can provide input on this.

#### 4.1.3.2 BATref control gear or ballast indoor

The proposed BATref Power efficiency of Luminaire is:
ηp = 1,00 or 100 %
dimming
Pc (luminaire control stand by power)(W): to be defined (TBD) W

The expected impact on product price of this solution is:
TBD

Examples and rationale for the selected data:
This value is the target value of EN 15193 but is related to the lamp (ηls = 140 lm/W) and luminaire efficacy (RLO = 1.00), hence the product of these two should be 140 lm/W. Details of this technology are explained in the light source study[180] and will not be repeated here.

#### 4.1.3.3 BATref luminaire and lamp efficacy indoor

The proposed BATref luminaire performance parameters are (see Task 1 for definitions):
ηls = 140 lm/W
FLLM @ 32000 h = 0.80
FLS @ 32000 h = 0.90
Cellular suspended: RLO = 1.00
CIE flux code: 0.67/0.94/0.98/0.36/1.00/0.75/1.00/1.00/0.64
Cellular ceiling mounted: RLO = 1.00

[184] https://en.wikipedia.org/wiki/Relay
[185] http://www.econation.be/ or http://www.warema.com/en/BUSINESS_PARTNERS/PRODUCTS/Light_guidance_systems/Index.php

CIE flux code: 0.64/0.92/0.98/1.00/1.00
Open plan suspended: RLO = 1.00
CIE flux code: 0.67/0.94/0.98/0.36/1.00/0.75/1.00/1.00/0.64
Open plan ceiling mounted: RLO = 1.00
CIE flux code: 0.64/0.92/0.98/1.00/1.00
Suspended: FLM = 1.00
Ceiling mounted: FLM = 1.00

The expected luminaire price for this solution is:
Suspended: 250 + X euro (excl. VAT)
Ceiling mounted: 250 + X euro (excl. VAT)
(This price includes design services)

Examples and rationale for the selected data:

The lamp efficacy and light output ratio values are the benchmark values for so-called expenditure factors in prEN 15193 but are related to the lamp (ηls = 140 lm/W) and luminaire efficacy (RLO = 1.00). Also the target maintenance factor FM = 0.80 = FLLM x FLM x FRSM will be used as suggested in prEN 15193, therefore FLM and FRSM are supposed to be 1.00.

It should be noted that in Regulation EC 245/2009 the indicative benchmark for FLM was > 0.95.

### 4.1.3.4 BATref Installation indoor

The proposed BATref installation parameters are (see Task 1 for definitions):
Cellular suspended: U = EN 13032 calculated with flux code = TBD
Cellular ceiling mounted: U = EN 13032 calculated with flux code = TBD
Open plan suspended: U = EN 13032 calculated with flux code = TBD
Open plan ceiling mounted: U = EN 13032 calculated with flux code = TBD
FRSM = 1.00
Reflectance ceiling/wall/floor: 0.7/0.5/0.2 (see Task 3)
FCL in cellular office = 1.25
FCL in open plan office = 1

Note: the respective reference geometries have been defined in Task 3.

The expected installation price for this solution is:
For installation times and associated cost per luminaire see Task 3.

Approach for design cost:
Included with the luminaire.

Examples and rationale for the selected data:

The Utilance is calculated with the flux code (EN 13032), which is incorporated in the project spreadsheet. The meaning and importance of Utilance is explained in Task 3; the improvement is achieved by selecting better optics for the task and/or placement of luminaires in the room. Another option to increase Utilance is increasing surface reflections, this can be discussed in a separate BAT improvement option.

### 4.1.3.5 Other BAT options at installation level indoor

In this section other BAT improvement options will be elaborated, for example:

BAT fit:

This is a solution wherein dimmable control gear is used to fit the illumination level exactly to the minimum required for the task area (500 lx). In the calculation spreadsheet this is implemented by correcting the amount of luminaires (2.44 instead of 3 in a cellular office).

BAT area:
This is a solution wherein luminaires and optics are arranged such that only the office desk area has the minimum required illumination level (500 lx) and the surrounding area the minimum required for the surrounding area (300 lx) (EN 12464). In a open plan the corridor area could be even less (100 lx), to be assessed in the final version. In the spreadsheet this is calculated by lowering the required average illuminance to 400 lx and modifying the number of luminaires (1.95 in cellular office).

BAT design01:
This is an individual design with high grade LED luminaires and higher reflecting wall surfaces that has been calculated with Dialux software. Afterwards the Dialux results were entered in the spreadsheets. In the spreadsheet there is an option to work with calculated illuminance values. Stakeholders are invited to supply similar Dialux design solutions, to be discussed in the stakeholder meeting.

BAT redefine area:
This is a solution for applications wherein the task area illumination requirements change over the life time of the building space, for example from office task area to cafeteria with meeting room and corridor. This is useful for the defined open plan office (Task 3). To be further elaborated in the final version. It is close to the previous 'BAT area' solution, whereby a flexible building management system can cope with this to redefine the individual task illumination levels.

BAT bright surface reflections:
This is the same as the BATref solution, but with bright surface reflections to increase the Utilance and use of daylight (see sections3.2.1.2.3 and 3.2.1.4).

### 4.1.4 BNAT or low energy using indoor lighting systems

**Approach:** In this section on BNAT or low energy use systems we are discussing the best systems that are under development but not on a stage of development which allows market introduction. They could also be used in later sections for modelling the impact of any future policy measures, to be considered if another category needs to be introduced for this in the event that this is deemed relevant and that data is available.

Stakeholders are invited to provide input such as ideas or calculated reference designs.

### 4.1.5 Worst case or high energy using road lighting systems

**Approach:** This section on Worst Case or high energy use systems considers the lowest performance that can enter the market after stage 3 of EC Regulation 245/2009. They could also be used in later sections for modelling the stock of existing systems, to be considered if another category needs to be introduced for this in the event that this is deemed relevant and that data is available.

#### *4.1.5.1 The WC control system and control gear level outdoor*

The WC control system following the definitions of EN 13201 is:

CLO regulation (EN 13201): none

t red (annual operating time at reduced illumination): 2000 h

k red (reduction coefficient for the illumination level): 1
$\eta p$ = 90 %

The expected impact on product price:
No additional costs

Examples and rationale for selected data:
The proposed selection is the least performing solution in EN 13201 where no constant light output regulation (CLO) is provided and there is no reduced light level during hours of low traffic. The ballast efficiency is according to Regulation 245/2009 stage 3 Table 16 on high intensity discharge lamps between 105 up to 405 Watt. There is also no dimming assumed after midnight during hours of low traffic (kred = 1).

### 4.1.5.2 WC luminaire and lamp efficacy outdoor

The proposed worst case luminaire performance parameters are (see Task 1 for definitions):

$\eta ls$ = 105 lm/W
FLLM @ 16000 h = 0.95
FLS @ 16000 h = 0.94
tgroup = 4 year (group replacement and cleaning period)
Road class M: RLO = 0.70
UFF = 0.05
Road class C: RLO = 0.70
UFF = 0.03
Road class P: RLO = 0.69
UFF = 0.57

Open luminaires: FLM = 0.51 (source CIE 154(2003): IP2x, medium pollution, 2 y cycle)

The expected luminaire price for this solution is:
Road class M: 180 euro (excl. VAT)
Road class C: 170 euro (excl. VAT)
Road class P: 140 euro (excl. VAT)

It is assumed that this price includes the design and calculation service (TBC)
So far poles are not included (TBC)

Examples and rationale for the selected data:
The worst case RLO values used for luminaire efficiency are sourced from the lot 9 street lighting study. Also the Upward Light Flux Fraction (UFF) is included, for example for road class P (Pedestrian) an omnidirectional globe luminaire is assumed that emits more light upward as downward to the road.
The lamp efficacy($\eta ls$) is the minimum according to Regulation 245/2009 stage 3 for an 105 up to 155 Watt HPS lamp.
The luminaire maintenance factor (FLM) was sourced from standard CIE 154 (2003) for an open luminaire (IP2x)(see lot 9).
The price is the lowest price from the lot 9 study on street lighting.

### 4.1.5.3 WC Installation outdoor

The proposed worst case installation parameters are (see Task 1 for definitions):
Road class M: U = 0.47
$FCL^{-1}$ = 1 + (1-250/150)/2 = 1.33
Road class C: U = 0.36
$FCL^{-1}$ = 1 + (1-150/100)/2 = 1.25
Road class P: U = 0.16
$FCL^{-1}$ = 1 + (1-100/70)/2 = 1.21

Note U values will be recalculated in the final version taking into account an update of the definition of the useful area (see Task 3), especially the road class M should be reviewed reconsidering the emergency lane and/or edge requirements.
Note: the respective reference road geometries and characteristics were defined in Task 3.

The expected installation price for this solution is:
For installation times and associated cost per luminaire see Task 3.

Approach for design cost:
Included with the luminaire.

Examples and rationale for the selected data:
The Utilance(U) is sourced from the lot 9 study but will be recalculated in the final version of this report. The meaning of the Utilance is explained in Task 3, it is mainly related to directing the light towards the road surface. In this case the luminaire optics and installation are not in the most effective way to direct all light from the light sources to the target road surface. It are the worst case luminaires for classes M and C with a poor reflector and balloon frosted lamps and for class P with an omnidirectional globe.
The correction factor for over-lighting (FCL) is calculated from the assumption that one has to select on average just in between two common available wattages, e.g 250 versus 150 Watt results in FCL = 1.33.

### 4.1.6 Mainstream or average energy using road lighting systems

**Approach:** This section on Mainstream or average energy use systems considers the modelling of an average performing road lighting installation that can enter the market in 2016. They could also be used in later sections for modelling the stock of existing systems, to be considered if another category needs to be introduced for this in the event that this is deemed relevant and that data is available.

#### *4.1.6.1 The MAINSTREAM control system and control gear level outdoor*

This is assumed to be similar to the Worst Case because advanced controls are not considered mainstream solutions in road lighting.

#### *4.1.6.2 MAINSTREAM luminaire and lamp efficacy outdoor*

The proposed mainstream luminaire performance parameters are (see Task 1 for definitions):

ηls = 105 lm/W
FLLM @ 16000 h = 0.95
FLS @ 16000 h = 0.94
tgroup = 4 year (group replacement and cleaning period)
Road class M: RLO = 0.73
UFF = 0.03
Road class C: RLO = 0.76
UFF = 0.00
Road class P: RLO = 0.71
UFF = 0.18

Closed luminaires: FLM = 0.86 (source CIE 154 (2003): IP5x, medium pollution, 2 y cycle)

The expected luminaire price for this solution is:
Road class M: 370 euro (excl. VAT)
Road class C: 220 euro (excl. VAT)

Road class P: 170 euro (excl. VAT)

It is assumed that this price includes the design and calculation service (TBC)

So far poles are not included (TBC)

Examples and rationale for the selected data:

The mainstream RLO values are average values sourced from the lot 9 street lighting study[186].

The lamp efficacy (ηls) is the minimum according to Regulation 245/2009 stage 3 for an 105 up to 155 Watt HPS lamp, which is considered an average wattage for this application.

The luminaire maintenance factor (FLM) was sourced from standard CIE 154 (2003) for an closed luminaire IP5X and cleaning cycle of 2 years.

The price is the average price from lot 9.

#### 4.1.6.3 MAINSTREAM Installation outdoor

The proposed mainstream installation parameters are (see Task 1 for definitions):

Road class M: U = 0.55

$FCL^{-1} = 1 + (1-250/150)/2 = 1.33$

Road class C: U =0.45

$FCL^{-1} = 1 + (1-150/100)/2 = 1.25$

Road class P: U = 0.20

$FCL^{-1} = 1 + (1-100/70)/2 = 1.21$

Note U values will be recalculated in the final version taking into account an update of the definition of the useful area (see Task 3).

Note: the respective reference geometries have been defined in Task 3.

The expected installation price for this solution is:

For installation times and associated cost per luminaire see Task 3.

Approach for design cost:

Included with the luminaire.

Examples and rationale for the selected data:

The Utilance (U) is sourced from the lot 9 study[186]. It is assumed that the average values for classes M and C with a standard reflector and mixed tubular clear and balloon frosted lamps are applicable. Class P is a mixture of luminaires and installations.

The correction factor for over-lighting (FCL) is calculated from the assumption that on average one has to select in between two common available wattage values, e.g 250 versus 150 Watt results in FCL = 1.33.

### 4.1.7 BAT or low energy using road lighting systems

**Approach:** This section on BAT or low energy use systems considers the best systems found on the market today. BATref is a reference BAT system with no specific installation-level improvement options implemented, apart from automation as modelled in EN13201-5, but other BAT options can be defined. They could also be used in later sections for modelling the impact of any future policy measures, to be considered if another category needs to be introduced for this in the event that this is deemed relevant and that data is available. They could also be used in later sections for modelling the stock of existing systems, to be considered if another category needs to be introduced for this in the event that this is deemed relevant and that data is available.

[186] http://www.eup4light.net/

#### 4.1.7.1 The BATref control system and control gear level outdoor

The BATref control system following the definitions of EN 13201 is:

CLO regulation (EN 13201): none
t red (annual operating time at reduced illumination): 2000 h
k red (reduction coefficient for the illumination level): 0.7
ηp = 94 %
Pc (luminaire control stand by power)(W): to be defined W

The expected impact on product price:

50 euro per luminaire?

Examples and rationale for selected data:

The proposed selection is the best performing solution in EN 13201 where constant light output regulation (CLO) is provided according to that standard. This assumes that there is a reduced light level during hours of low traffic with approximately 30 % light level reduction of class M3 (1 Cd/m²) to class M4 (0.75 Cd/m²) (kred = 0.7 during 2000 h). The ballast efficiency is the best that has been found on the market.

#### 4.1.7.2 BATref luminaire and lamp efficacy outdoor

The proposed BATref luminaire performance parameters (see Task 1 for definitions) are:

ηls = 140 lm/W
FLLM @ 100000 h = 0.80
FLS @ 16000 h = 0.99
tgroup = 4 year (group replacement and cleaning period)

| | | |
|---|---|---|
| Road class M: | RLO = 1.00 | UFF = 0.02 |
| Road class C: | RLO = 1.00 | UFF = 0.02 |
| Road class P: | RLO = 1.00 | UFF = 0.02 |

Closed luminaires: FLM = 0.89 (source CIE 154 (2003): IP6x, medium pollution, 2 y cycle)

The expected luminaire price for this solution is:

| | |
|---|---|
| Road class M: | 1000 euro (excl. VAT) |
| Road class C: | 750 euro (excl. VAT) |
| Road class P: | 500 euro (excl. VAT) |

It is assumed that this price includes the design and calculation service (TBC)
So far poles are not included (TBC)

Examples and rationale for the selected data:

The BAT reference RLO values are average values sourced from the lot 9 street lighting study[187].
The lamp efficacy(ηls) is the same target value as for indoor lighting.
The Lumen Maintenance Values (FLLM) is compliant with the value that is most often cited in LED luminaire manufacturers catalogues.
The luminaire maintenance factor (FLM) was sourced from the standard CIE 154 (2003) for a closed luminaire IP6X and cleaning cycle of 2 years.
The price is estimated from online retailer websites[188], [183] but will be updated in the course of this study.

[187] http://www.eup4light.net/

#### 4.1.7.3 BATref installation outdoor

The proposed BATref installation parameters are (see Task 1 for definitions):

Road class M: U = 0.70
$F_{CL}^{-1}$ = 1

Road class C: U = 0.70
$F_{CL}^{-1}$ = 1

Road class P: U = 0.60
$F_{CL}^{-1}$ = 1

Note U values will be recalculated in the final version taking into account an update of the definition of the useful area (see Task 3) after discussion in the stakeholder meeting.

Note: the respective reference geometries have been defined in Task 3.

The expected installation price for this solution is:

For installation times and associated cost per luminaire see Task 3.

Approach for design cost:

Included with the luminaire.

Examples and rationale for the selected data:

The Utilance (U) will be based on software calculations, stakeholder can provide input. A Dialux file with the reference design will be available for this purpose, calculated average maintained illuminance for the areas can be introduced in the project spreadsheet.

The correction factor for over-lighting ($F_{CL}$) assumes dimmable control gear and a constant and perfect fit to the minimum required illumination.

#### 4.1.7.4 BAT other installation

In this section other BAT improvement options will be elaborated, for example:

BAT case01 for application Motorized Road M3:

In this application a specific street lighting design was calculated with Dialux based on LED luminaires and entered in the spreadsheet. Stakeholders are invited to supply similar Dialux design solutions, to be discussed in the stakeholder meeting.

#### 4.1.7.5 BNAT outdoor installation

Other solutions under development can be proposed herein. Stakeholders are invited to supply information.

## 4.2 Production, distribution and End of Life

**Objective:** The objective of this section is to consider environmental impacts from the 'production' and 'distribution' of lighting systems. Material flows and collection effort at end-of-life, to landfill/incineration/recycling/re-use should also be modelled. Please note that the MEErP methodology uses the EcoReport Tool which is a spreadsheet that models production according to Bill-Of-Materials and the volume of packed material and recycling ratios and methods.

**Proposed approach:**

[188] www.voltus.de

Much of the design work is does not consume materials and has to be done by local designers and installers with little need for transport. Lighting Systems are not disposed of as a whole but is related to disposal of the components. Therefore it is assumed that this is covered by the MELISA model from the Light Sources study[189] using the MELISA model, see also Task 2. To model this impact a sales factor (Fsales) is introduced in MELISA., see Task 2. The (Fsales)factor is also calculated in the spreadsheet developed in this Task 4.
This means that other factors will be neglected, such as wall painting, light poles, cabling, etc.

## 4.3 Summary of lighting system technical solutions and technical improvement options

This section summarises, calculates and compares the energy performance parameters from the improvements and parameters discussed in the previous sections for the selected reference applications defined in Task 3. Formulae were sourced from prEN15193 or prEN 13201-5 in line with those defined in Task 1 and 3. These formulae are included in a spreadsheet which is complementary to this report. This spreadsheet is available on request for stakeholders who want to contribute. All data from previous sections is entered in this spreadsheet. There follows a brief discussion on the outcomes.

**Discussion of the results for indoor lighting:**

The calculated outcomes on annual energy consumption for the defined cellular office with ceiling-mounted luminaires applications are summarised in Table 4-1 for the different design options that were previously discussed. The Lighting Energy Numerical Indicator (LENI, EN 15193) for the Worst Case design is 56 kWh/m²y, for the mainstream is 26 kWh/m²y and the best of BAT is 5.7 kWh/m²y. It is also clear that such a high improvement potential is not only due to an increase of the light source efficacy from 75 lm/W up to an expected 140 lm/W for LED luminaires but is related to a combination of factors. These outcomes are in line with the TEK tool discussed in section 1.5.2.4 in Task 1 and therefore seem to be reliable. Table 4-1 also includes some expenditure factors sourced from prEN15193 and supplementary factors included in this study. These expenditure factors can provide insight into how far sublevels are optimised compared to the benchmark. This could be further elaborated and documented in the final version. Is this useful?

[189] http://ecodesign-lightsources.eu/

*Table 4-1 Annual Lighting Energy consumption and installation efficacy calculated for a cellular office with ceiling mounted luminaires in Worst Case(WC), mainstream and BAT lighting designs*

| Reference design | lot 37 WC | lot 37 Mainstream | lot 37 BATref | lot 37 BATfit | lot 37 BATarea | lot 37 BATdesign01 |
|---|---|---|---|---|---|---|
| ηls (lm/W) =ηL (25°C standard conditions) | 75,00 | 86,00 | 140,00 | 140,00 | 140,00 | 110,94 |
| FLLM (lamp lumen maintenance f) (=f(t-lamp replacement period)) | 0,90 | 0,90 | 0,80 | 0,80 | 0,80 | 0,80 |
| ηp = fB (power efficiency of luminaire) | 0,76 | 0,84 | 1,00 | 1,00 | 1,00 | 1,00 |
| CIE flux code N5(RLO) (Luminaire light output ratio) | 0,47 | 0,68 | 1,00 | 1,00 | 1,00 | 1,00 |
| FLM (Luminaire Maintenance Factor) | 0,91 | 0,91 | 1,00 | 1,00 | 1,00 | 1,00 |
| FRSM (Room Surface Maintenance Factor) | 0,96 | 0,96 | 0,96 | 0,96 | 0,96 | 0,96 |
| constant illumination control(EN 15193) | n | n | y | y | y | y |
| occupancy control type(EN 15193) | Man. On/Off | Auto On/Off | presence det. | presence det. | presence det. | presence det. |
| room type absence (EN 15193) | Cellular 2-6 p. | Cellular 2-6 p. | Cellular 2-6 p. | Cellular 2-6 p. | Cellular 2-6 p. | Cellular 2-6 p. |
| type of daylight control (Table F.16) (EN 15193) | I: Manual | I: Manual | VIII: nSB nSW | VIII: nSB nSW | VIII: nSB nSW | VIII: nSB nSW |
| type of blinds control (annex F 3.2.4) (EN 15193) | MO | MO | Auto | Auto | Auto | Auto |
| U (utilance) = ηR (software or flux code) | 0,64 | 0,74 | 0,74 | 0,74 | 0,74 | 0,81 |
| eL,C (eq. 18) part. expend. 4 const. Illum. control | 1,00 | 1,00 | 1,01 | 1,01 | 1,01 | 1,01 |
| eL,O (eq. 19) part. expend. 4 occupancy control | 1,29 | 1,14 | 1,21 | 1,21 | 1,21 | 1,21 |
| eL,D (eq. 19) part. expend. 4 daylight dep. control | 1,11 | 1,11 | 1,09 | 1,09 | 1,09 | 1,09 |
| **eE (eff. For fitting to minimum requirements** | 1,23 | 1,23 | 1,23 | 1,00 | 1,00 | 0,91 |
| eL,ES, del (eq. 19) part. expend. 4 delivery of light | 1,12 | 0,97 | 0,97 | 0,97 | 0,97 | 0,88 |
| eL,ES, dis (eq. 19) part. expend. 4 distrub. of light | 2,13 | 1,48 | 1,00 | 1,00 | 1,00 | 1,00 |
| eL,ES, gen (eq. 19) part. expend. 4 generation of light | 1,42 | 1,37 | 1,00 | 1,00 | 1,00 | 1,26 |
| eLES (eq. 19) part. Expend. 4 lighting system | 3,39 | 1,96 | 0,97 | 0,97 | 0,97 | 1,12 |
| **LENI (kWh/m²Y) (f 15)** | 55,8 | 27,5 | 9,8 | 8,0 | 6,4 | 8,4 |
| **ηinst-u (usefull installation efficacy) (lm/W)** | 13,56 | 28,63 | 88,75 | 88,75 | 88,75 | 76,95 |
| **Fhour-s (=(Fox(Fdxtd+tn)/(td+tn)** | 0,82 | 0,73 | 0,57 | 0,57 | 0,57 | 0,57 |

As an experiment, Table 4-1 also includes the concept of partial expenditure factors that is under development in prEN15193. Partial expenditure factors can be useful to provide insight into how far a system is optimised compared to benchmark values. The lower its values the better, in most cases the theoretical best values is '1'.
The following expenditure factors are defined (prEN 15193):
eL,C: Partial expenditure factor for constant illuminance control
eL,O: Partial expenditure factor for occupancy dependant lighting control
eL,D: Partial expenditure factor for daylight dependant lighting control
eL,ES: Partial expenditure factor for the electric lighting system
eL,ES,del: Partial expenditure factor for delivery of electric light
eL,ES,dis: Partial expenditure factor for distribution of electric light
eL,ES,gen: Partial expenditure factor for generation of electric light

Similar calculations were done for road lighting, the results are summarised in Table 4-2 for Worst Case(WC), mainstream and BAT lighting designs. It shows that the installation efficacy can range from 11.3 up to 76.6 lm/W with a corresponding Annual Energy Consumption Indicator (AECI, prEN 13201-5) of 5.06 to 0.63 kWh/(m²y) and a lighting power density (PD, prEN 13201-5) from 0.066 to 0.015 W/m².lx. Clearly also here again, this improvement is not only related to the improvement of the light source efficacy but is due to a combination of several improvement options.

*Table 4-2 Annual Energy Consumption Indicator and installation efficacy calculated for a motorized road with lighting class M3*

| lamp type | | NN | NN | LED | LED | LED |
|---|---|---|---|---|---|---|
| | | WC | Mainstream | BATref | BATcase01 LED | BATcase02 LED |
| source | | lot 37 | lot 37 | lot 37 | lot 37 | lot 37 |
| FLLM | | 0,95 | 0,87 | 0,80 | 0,87 | 0,87 |
| ηp | | 0,90 | 0,90 | 0,94 | 1,00 | 1,00 |
| ηls (calculated from Pls and Lamp lumen) | lm/W | 105,00 | 105,00 | 140,00 | 92,00 | 92,00 |
| FLM | | 0,51 | 0,86 | 0,89 | 0,89 | 0,89 |
| fM=MF = LMF*LLMF=FLM*FLLM | | 0,48 | 0,75 | 0,71 | 0,77 | 0,77 |
| CIE flux code N5(LOR) = ηLB=RLO | | 0,70 | 0,73 | 1,00 | 1,00 | 1,00 |
| t full (annual operating time at full illumination) | h/y | 2000 | 2000 | 2000 | 2000 | 2000 |
| t red (annual operating time at reduced illumination) | h/y | 2000 | 2000 | 2000 | 2000 | 2000 |
| k red (reduction coefficient for the illumination level) | | 1,00 | 1,00 | 0,70 | 0,70 | 0,70 |
| U (Utilance) from selected method | | 0,47 | **0,48** | 0,70 | 0,59 | 0,59 |
| FCL = correction for not fitting minimum requirements | | 0,75 | 0,75 | 1,00 | 1,24 | 1,00 |
| CLO regulation | y/n | n | n | y | y | y |
| Fclo =(1-(1-Fm)/2)xCL | | 1,00 | 1,00 | 0,85 | 1,10 | 0,88 |
| ηinst | lm/W | 11,3 | 18,4 | 76,6 | 47,1 | 47,1 |
| DP (PDI) (no FCLO & no CL) (lighting power density) | W/(m².lx)=W/lm | 0,066 | 0,041 | 0,015 | 0,024 | 0,024 |
| DE (AECI) = Px(tfull+kredxtred)xFclo/A (excl. edges area) (annual energy) | kWh/(m².y) | 5,036 | 2,772 | 0,63 | 0,80 | 0,80 |
| Fhour-abs =(td + kredxtred)/(td+tred) | | 1,000 | 1,000 | 0,850 | 0,850 | 0,850 |

## 4.4 Recommendations

To be elaborated in the final version.