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'Lot 37'

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LIST OF ACRONYMS

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 Reliability
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 Addressable LIghting
DFF	Downward light Flux Fraction
DIS	Design Improvement Scenario
DIY	Do-It-Yourself
DLOR	Downward Light Output Ratio
DLS	Directional Light Sources
DMX	Digital Multiplexing
DoE	Department of Energy
DP	Lighting power density indictor
EC	European Commission
Ecyl	Cylindrical illuminance
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
Evert	Vertical illuminance
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	Harmonised 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 optimisation
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 optimisation
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 optimisation
Q0	Average luminance coefficient
R_a	Colour rendering index
RD	Reference Design
REACH	Registration, Evaluation, Authorisation and Restriction of Chemical substances.
RES	Renewable Energy Sources
RLO	light output ratio
RLOW	light output ratio working
RoHS	Restrictions 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
Uo	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

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Executive summary

This study was done under a framework contract (ENER/C3/2012-418 Lot 1) for preparing the implementation of the Ecodesign or Energy Related Products (EED) Directive (2009/125/EC) related to lighting systems on behalf of the European Commission Directorate-General for Energy -Energy Efficiency Unit.

According to the principle of better regulation, preparatory studies will collect evidence, explore all policy options and recommend the best policy mix, 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 was 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 MEErP consist of:
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 Best Available Technology (BAT) and Best Not Yet Available Technology (BNAT));
Task 5 – Environment & Economics (base case Life Cycle Assessment (LCA) & Life Cycle Costs (LCC)) (not in this study);
Task 6 – Design options(improvement potential) (not in this study);
Task 7 – Scenarios (Policy, scenario, impact and sensitivity analysis). .
Task 0 or a Quick-scan is optional to Task 1.

In a multi stakeholder consultation, a number of groups and experts provided comments and input on a preliminary draft of this report. The report was then revised, benefiting from stakeholder perspectives and input. 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. A list of stakeholders that participated in this consultation and further information on project meetings, project website and comments can be found in Annexes G to L.

Task 1

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 measurable quality parameters as described in European standards such as EN 12464-1 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 or lamp, 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. Task 1 provided the rationale for this scope selection.

Non-residential lighting design, as defined in the standards series EN 12464-1 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. Task 1 therefore also explains how the system can be decomposed into subsystems and introduces the main parameters specified within the European and international standards to do this. 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,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 or lighting systems 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 EN 15193 plays an important role for indoor lighting, as does EN 13201-5 for road lighting. These provisions within these draft standards are respected to the extent possible within this study.

Task 1 also included a Task 0 (Annex M) with a first screening on potential energy impact, but these values benefited from more accurate data in later tasks and are updated in Task 7.

Task 2

A lighting system somehow differs from other products examined in ecodesign preparatory studies as it is designed in advance but 'assembled in situ' rather than produced, imported or exported as a whole. Consequently lighting systems are not distinguished as traded products in the Eurostat Prodcom statistics. Data are available for some of the lighting system components such as light sources, control gears, luminaires and some lighting controls, and these data are reported in this chapter.

In the absence of direct market data it is anyway possible to estimate the energy savings due to lighting system improvements by linking the Task 7 scenario analysis to the 'Model for European Light Sources Analysis' (MELISA), that has been developed in the Ecodesign preparatory study on Light Sources. A complication is that MELISA data all refer to light sources and not to luminaires or to buildings or spaces to be illuminated, which is the focus of the Lighting Systems study. To circumvent this problem, reference will be made to the total sold and installed luminous flux of MELISA and to the total full-power equivalent annual operating hours. Two factors will be used to model the influence of lighting system improvements in MELISA, the so-called Flux Factor F_{phi} and the Hour Factor F_{hour}. MELISA already includes energy savings due to improvements in light source efficacy. Linking the Systems analysis to MELISA using only the factors F_{phi} and F_{hour} avoids double counting of these savings.

In general, the factors F_{phi} and F_{hour} will differ between reference cases (e.g. different optimisation possibilities for offices, corridors, manufacturing halls, warehouses, shops, motorways, secondary roads, roads in residential quarters). Energy weighted-

averages for F_{phi} and F_{hour} over all reference cases are required for use in MELISA. For this purpose LENI or AECI energy density values in kWh/m^2/y will be derived for the optimisation options of the reference cases in Task 4. These values can be multiplied by the total EU-28 areas (m^2) per reference case to obtain the total EU-28 energy consumption per reference case. The subdivision of the total EU-28 non-residential building area over the reference cases and the subdivision of the total EU-28 lit road length over the road types are estimated in this chapter.
The building area subdivision indicates that in addition to office spaces the lighting energy consumption in circulation and sanitary areas, manufacturing areas, storeroom/warehouses and shops is also significant. This will be taken into account when selecting the reference cases in Task 4.

Task 3

This task identified and provided 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 designs or applications used in those studies are reused here. Moreover, based on the Task 2 market data and in consultation with stakeholders new Reference Applications were defined to cover a more representative set of EU non-residential indoor lighting applications. they are:

- A cellular office with ceiling mounted luminaires (cellular ceiling mounted);
- A cellular office with suspended luminaires (cellular suspended);
- An open plan office with ceiling mounted luminaires (open ceiling mounted);
- An open plan office with suspended luminaires (open suspended);
- A corridor in a building (corridor);
- A large Do-it-Yourself store (Large DIY);
- A supermarket(supermarket);
- A large indoor industrial plant (Industry Large);
- A small industry workshop (workhop);
- A large warehouse with optionally some lit racks (warehouse).

For each of these indoor applications different zones(area's) were defined with their minimum lighting design requirements in accordance with EN 12464-1 For example vertical illuminance requirements(Evert) were added in the supermarket to illuminate properly the shelves and cylindrical illuminance requirements(Ecyl) were added in the offices to increase facial recognition and communication. The main parameters are explained in Task 1. An east window orientation located in Frankfurt was selected to provide EU28 average daylight conditions for reference applications in Task 4.

For road lighting the reference applications were selected in accordance with the market data from Task 2, they are:

- A motorway EN 13201 class M2 with 4 lanes total;
- A main or national roads class M3 with two car traffic lanes;
- A secondary rural roads with two car traffic lanes and pedestrian/parking lanes(M4&P4);
- A secondary road with mixed traffic and six lanes(C3);
- A residential area road with mixed traffic class P2 and single sided luminaire arrangement;
- A residential street class P4 and staggered luminaire arrangement;
- A residential street class M5 with two car traffic lanes and pedestrian/parking lanes class P5.

The main design parameters for the road lighting reference applications were selected in accordance with EN 13201-2.

To model the impact of the use-phase energy calculations are proposed in line with standards EN 15193 for indoor lighting and EN 13201-5. In this Task reference design data is included for the selected applications and also potential deviations under real circumstances are discussed that could serve afterwards for sensitivity analysis.

Task 4

In this task the current sales base case is compared with different BAT options for each of the reference applications that were defined in Task 3. All designs were produced using lighting design software. Most designs were supplied by experienced lighting designers from seven different lighting manufacturers. The calculated outcomes for indoor lighting are expressed in terms of the Lighting Energy Numerical Indicator (LENI)[kWh/(y.m²)] as defined in EN 15193. Similar results were obtained for outdoor lighting that were calculated in line with the standard EN 13201-5 and that contain the Annual Energy Consumption Indicator (AECI))[kWh/(y.m²)] and the Power Density Indicator (PDI) [W/(lx.m²)]. For all designs detailed subsystem/component parameters are collected in line with the subsystem definitions of Task 1 (installation parameters, luminaire parameters, ..). These parameters also provides insight into what the system design improvement potential is, and enables the calculation of improvement policy scenarios in Task 7 that are independent of the efficacy improvement of the light source itself. Relevant cost data is also presented per design option. From the results it is clear that the high improvement potential is not due only to an increase in light source efficacy but also to several other lighting system factors and thus that the improvement potential is a combination of many design options and parameters.
Where applicable the following design options are considered for indoor reference applications:

- 'BC' means the current sales base case, which is a low cost simple design which still satisfies the minimum requirements of EN 12464-1. These designs were created with non-LED products but could of course also be made with comparable LED products, such as retrofit LED tubes. BC could therefore also be considered as a 'basicLED' design, when taking the LED efficacy improvement into account of the light source study. Note that they already satisfy the EN 12464-1 requirements hence in practice significantly worse systems are installed.
- 'BATLED' means the best fit with luminaire optics and layout. It uses LED luminaires for which the optics and layout are carefully selected to yield to the best results.
- 'BATsmart' is the BATLED but combined with the most advanced lighting controls defined in EN 15193.
- 'BATbright' is BATsmart combined with increased surface reflections for reference designs where this is considered possible.
- 'BATday' is BATsmart with the addition of roof lights for increasing the daylight contribution for reference designs where this is considered possible.

For road lighting the following design options were elaborated:

- 'BC' means the current sales base case, which is a low cost simple design which still satisfies the minimum requirements of EN 13201-2. These designs were created with non-LED products but could of course also be made with comparable LED products. Note that they already satisfy the EN 13201-2 requirements and basic design selection rules were applied, hence in practice it is likely that much worse systems are installed.

- 'LEDdesign' means the best fit with precisely selected luminaire optics with LED and design practices as supplied by the participating designers from four different lighting manufacturers[196] .
- 'LEDsmart is the 'LEDdesign' option but with the best smart controls as defined in EN 13201-5.

All lighting designs are according to minimum measurable EN 12464-1 and/or EN 13201-1 lighting design requirements that are defined per reference design in Task 3.

The LENI results [kWh/y.m²)] obtained for the reference applications defined in Task 3 for various design options are summarised in Figure 0-1. The AECI [kWh/(m².y)] and PDI[W/(lx.m²)] results obtained for the reference roads of Task 4 are summarised in Figure 0-2 and Figure 0-3.

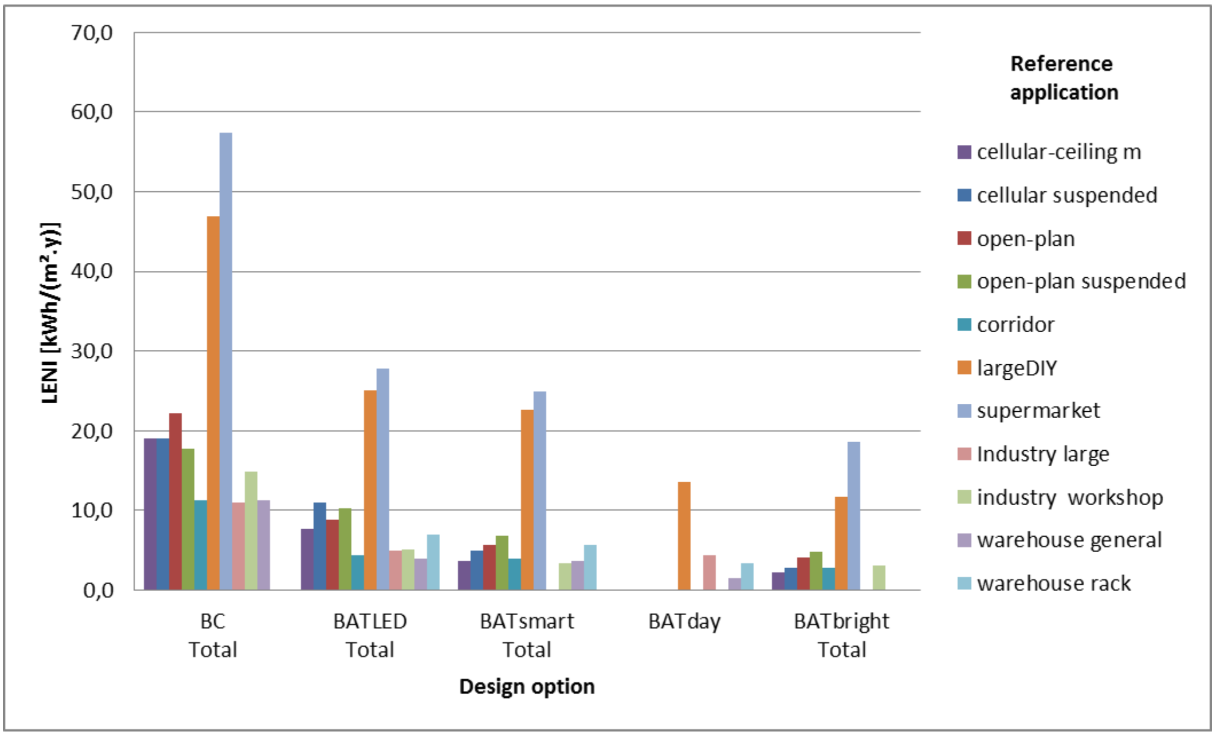

Figure 0-1 Calculated LENI values per reference indoor application for various lighting design options

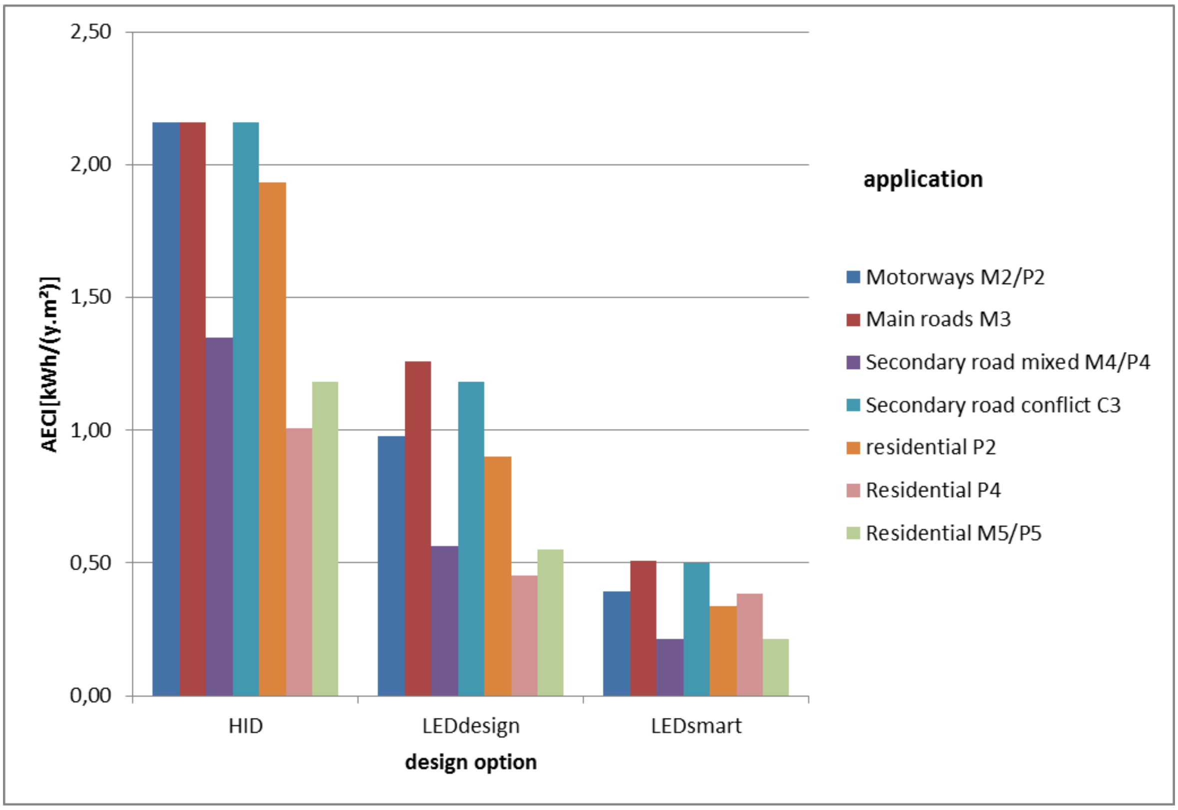

Figure 0-2 Calculated AECI values per reference road for various lighting design options

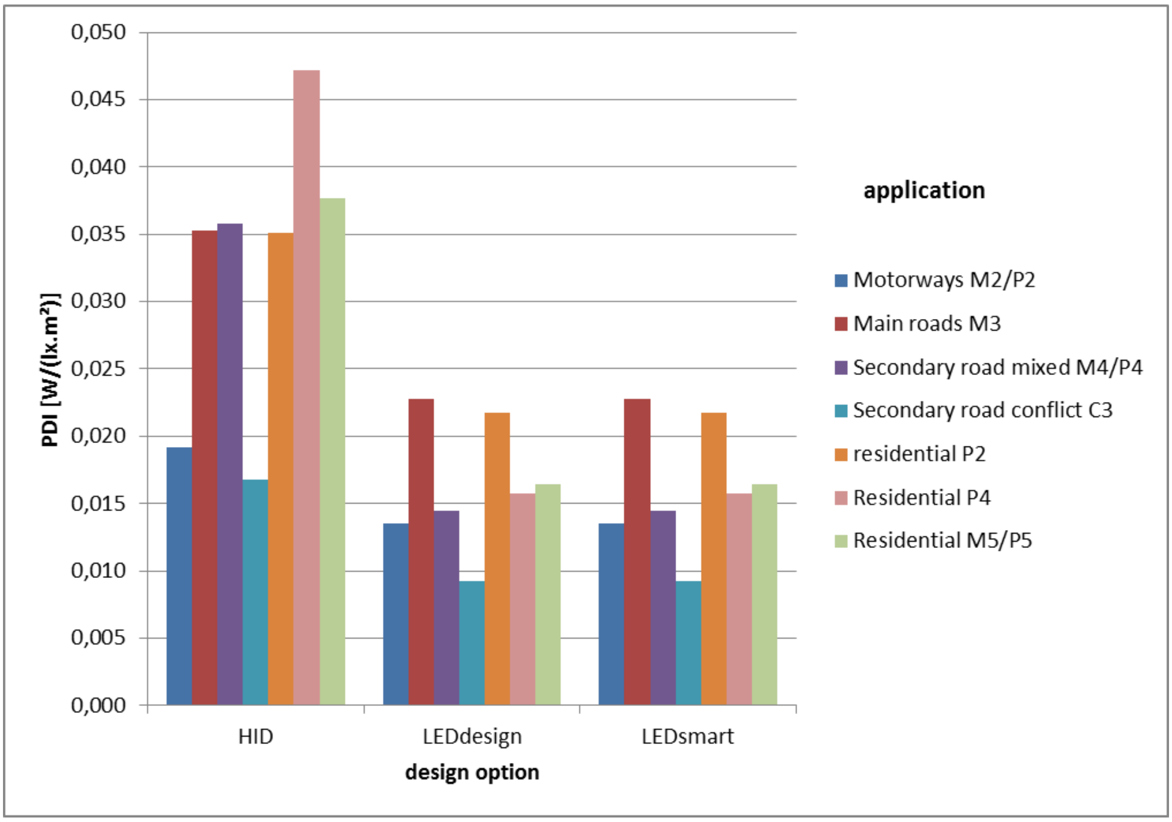

Figure 0-3 Calculated PDI values per reference road for various lighting design options

Apart from improved light source efficacy in road lighting the improvement of Utilance and smart controls also contribute to a large potential AECI reduction. For indoor lighting smart controls, increased surface reflection and to a lesser extent improved utilance contribute to lower potential LENI values. For example in a cellular office LENI could be reduced from 19 kWh/(y.m²) with lamp efficacy of 90 lm/w to 12.6 kWh/(y.m²) with LED Efficacy of 136 lm/W to 2.2 kWh/(y.m²) with LED and all other lighting system design improvement options implemented (extra lighting controls, increased surface reflectance, better lay out planning and optical arrangement)., Hence the majority of the reduction in the LENI is related to other factors than lamp efficacy improvement.
Finally it should be noted that while these improvements were calculated according to the state of art defined in EN 13201-5:2016 and prEN 15193-1:2016 that also so-called BNAT lighting design techniques and systems were identified that go beyond these. Hence, in future even lower LENI and AECI values can be expected compared to what has been calculated in this task.

Task 7

A first section 7.1 considers the scope of application of potential lighting system measures which fall within the purview of the Ecodesign policy options and scenarios. It proposes scope definitions but also discusses the issue of considering an installed lighting system as a 'product' within the scope of potential Ecodesign measures.

A second section 7.2 considers the barriers to lighting system energy efficiency and describes the policy instruments which are available to help address them. It compares policy instruments such the Ecodesign (ED)(2009/125/EC), Energy Labelling (ELD) (2010/30/EU), Energy Performance of Buildings (EPBD) (2010/31/EU) and the Energy Efficiency Directive (EED) (2012/27/EU). In general all of these policy instruments could contribute and section 7.3 puts forward a set of specific policy proposals aimed at improving the environmental and economic performance of lighting systems. Explicitly, the policy measures proposed in section 7.3 consider how new lighting designs can be encouraged to be more in line with best available technology solutions as determined in Task 4 of the report. The measures include a mixture of regulatory requirements, implemented via policy instruments such as Ecodesign Regulations, Building Codes, Highway Codes/ordinances and Energy Labelling regulations; and softer options using incentives, awareness and capacity building measures. Note that product requirements can for example also be a complement to lighting system requirements, e.g. requirements for components such as controls or luminaires to be used in certain type of lighting system.

The impact assessments in sections 7.4 and 7.5 consider the broader impacts of such policy actions and provide a general indication of the costs and benefits they would entail. In a full study, including tasks 5 on Environment & Economics and Task 6 on Design options, the economic optimization and its impact could be more elaborated. Despite these tasks were not performed, the study was able to estimate the potential impact on EU annual energy consumption by linking the improved lighting design techniques of Task 4 to the 'Model for European Light Sources Analysis' (MELISA). The MELISA model was developed during the Lot 8/9/19 ecodesign preparatory study on light sources[1] and contains the EU reference electricity consumption for lighting. Using MELISA, savings deriving from light source efficiency improvements can be clearly discriminated from savings due to the lighting system improvements investigated in

[1] See: http://ecodesign-lightsources.eu

Task 4. The policy measures related to the light source study are still under discussion (October 2016) and hence energy impacts due to lighting system improvements have been evaluated for three reference light source scenarios presented in the Lot 8/9/19 light source study:

- BAU scenario (no new regulations on light sources),
- ECO 80+120 scenario (phase-out of all classical lighting technologies between 2020 and 2024; accelerated adoption of LEDs), and
- ECO 80+120+LBL scenario (same as previous but assuming additional energy labelling improvements; higher average efficacy for LEDs).

The maximum EU-28 total savings for optimised lighting system designs with controls are depending on the reference light source scenario and the maximum EU-28 total annual electricity savings due to lighting system measures are 20-29 TWh/a in 2030 and 48-56 TWh/a in 2050. This is approximately 10% (2030) or 20% (2050) of the total EU-28 electricity consumption for non-residential lighting in the BAU-scenario for light sources.
Because of the long life time of lighting installations, reaching the full impact of lighting system measures will take several decades. The ECO 80+120 light source scenario would accelerate the transition to LED luminaires due to a phase-out of inefficient LFL, CFLni or HID lamp types, and hence would also accelerate the impact of lighting system design and control system policy options proposed in this study. Viceversa, the proposed lighting system measures can also contribute to achieving the energy savings estimated in the light sources study, even without an imposed accelerated switch to LEDs: selection of efficient light sources is anyway necessary to obtain low LENI or AECI values.

The analysis of market data showed that the indoor reference cases of Task 4 covered 63% of the total electricity consumption for indoor non-residential fluorescent lighting and 61% of the total HID-related electricity consumption.

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)[2] 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.

[2] 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).

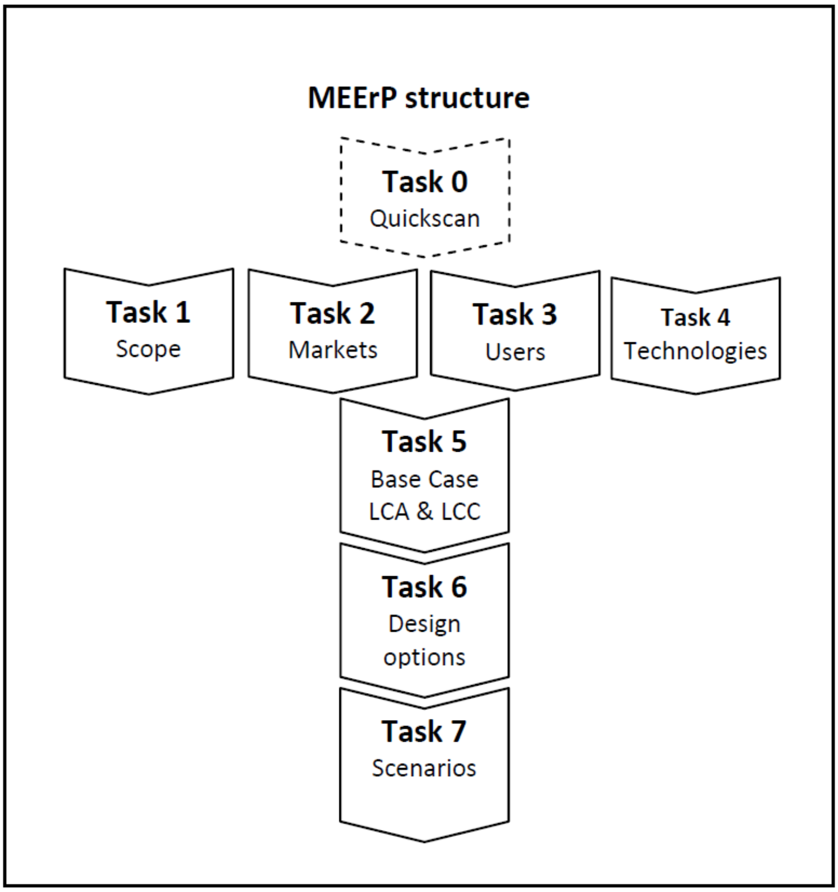

Figure 0-1: MEErP structure

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 related to lighting are in place today, all having a different specific scope:

- **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.
- **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 able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council.
- **Commission Regulation (EC) No 1194/2012** 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** 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, and if there are loopholes in the existing legislation in relation to lighting systems..

0.3 Lighting systems

This study looks at the application of lighting and the used technical building system or installation for this purpose. 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 an installation with 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. Note that in case of a fixed integration of LED modules within the luminaire there is no strict separation between lamp and luminaire as which was common practice with non-LED lamps. This has an impact on product terminology used in standards and legislation. Light sources are studie in a separate study that runned in parallel to this system study[3]. 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'. More specific in the context of this study Tasks 3&4 a lighting system means a system of devices intended to deliver effective lighting to create a comfortable , functional and safe environment for human habitation , travel, work and leisure activities.

Lighting schemes are the theoretical planning of a lighting system and allow for the evaluation of these systems at early stages. 'Lighting control 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

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

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 lighting system components are[4,5]:

- **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)[6]. 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;
- **Occupancy/presence detection sensor**
  A device that measures the light (light sensor) or that detects the occupancy/presence of persons (presence detection sensor);
- **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;

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

- **Lighting communication network**
  A network throughout the building between lighting fixture and controls components, such as sensors and switches, which have bidirectional communication. A lighting communication network can be part of a building communication system (HBES/BACS).

In case of a fixed integration of LED modules within the luminaire there is no strict separation between lamp and luminaire as which was common practice with non-LED lamps. This can for example have an impact on product terminology used in standards and legislation.
This study started in 2013 and did follow the governing definitions in the existing standards at the time being related to indoor and road lighting design. However in view of new LED product developments terminology and standards are likely to be updated accordingly. Establishing these standards and definition however is an ongoing process, for example IEC TC34 is working on 'lighting systems and related equipment vocabulary'. This means that the terminology and definitions used in this study will not necessarily match the future ones. For example updates or reviews might better define the herein so-called 'lamp' (FLLM) and 'luminaire'(FLM) maintenance factors that model light output depreciation for LED. Also note that this study will follow already the new approach of defining acronyms in lighting, e.g. LLMF(e.g. EN 15193:2007, EC Regulation 245/2009, ..) is replaced by FLLM (EN 12665:2011).
Despite that some definitions were still under review or might change in future, this did not stop the study from analysing system performance and improvement potential in Tasks 3&4. It means that the outcomes of this study on system performance remain valid but that in some cases the definitions and terminology might need to be updated according to the state of art before applying them.
Note also that light sources are studied in a separate study[7] that runned in parallel to this system study and therefore they are not analysed in detail in this study.

0.4 Key characteristics of lighting systems

Measurable 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. Note that these standards include the typical minimum quality parameters for applications where such specifications are used but that they do necessarily provide the best quality in any application, e.g. ambient lighting in restaurants or decorative lighting in outdoor applications.

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[5] 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

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

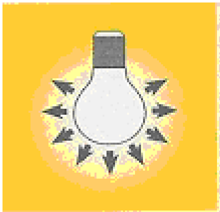

Figure 0-2: Luminous flux

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

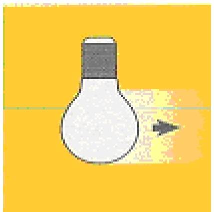

Figure 0-3: Luminous intensity

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 12665:2011.

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].

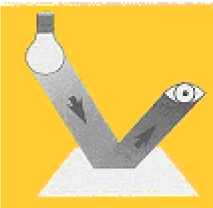

Figure 0-5: Luminance

0.4.5 Perceived colour

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

Perceived colour is defined[5] 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[5] 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[4] 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:

- Measured photometric performance and photometric file
- Rated input luminaire power (W)
- Rated Luminaire Luminous Flux (lm)
- 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 (LMF)
- Lamp Survival Factor (LSF)
- 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

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 measurable quality of light & lighting are of primary importance in many applications where specifications are made in the procurement process. Lighting system design in many applications is therefore based on minimum measurable 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 by 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[8]. In this study we will focus on many other improvement options to lower the impact and energy consumption of installed lighting systems, such as controls, wall reflectance, optics, etc.

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

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

part of the light that does not illuminate the targeted area is considered to be un-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

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 measurable 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 or lamp, 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 12464-1 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 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 1-3It 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 categorybecause 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 lighting system 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 EN 15193 plays an important role for indoor lighting, as does EN 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 Task4 and 7.

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 categorisations:

- 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’ according to the definition of the Ecodesign Directive. Note that in other legal acts, the definition is usually not a broad.

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). A lighting system means a system of devices intended to deliver effective lighting to create a comfortable, functional and safe environment for human habitation , travel, work and leisure activities. 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. This means that or example a luminaire, lamp, etc. are only a component in the lighting system. 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[9]. 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[10]. 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.

[9] www.licht.de : Guide to DIN EN 12464-1 Lighting of work places –Part 1: Indoor work places, ISBN: 978-3-926193-89-6

[10] www.licht.de : Guide No. 03, 'Roads, Paths and Squares, ISBN 978-3-926193-93-3

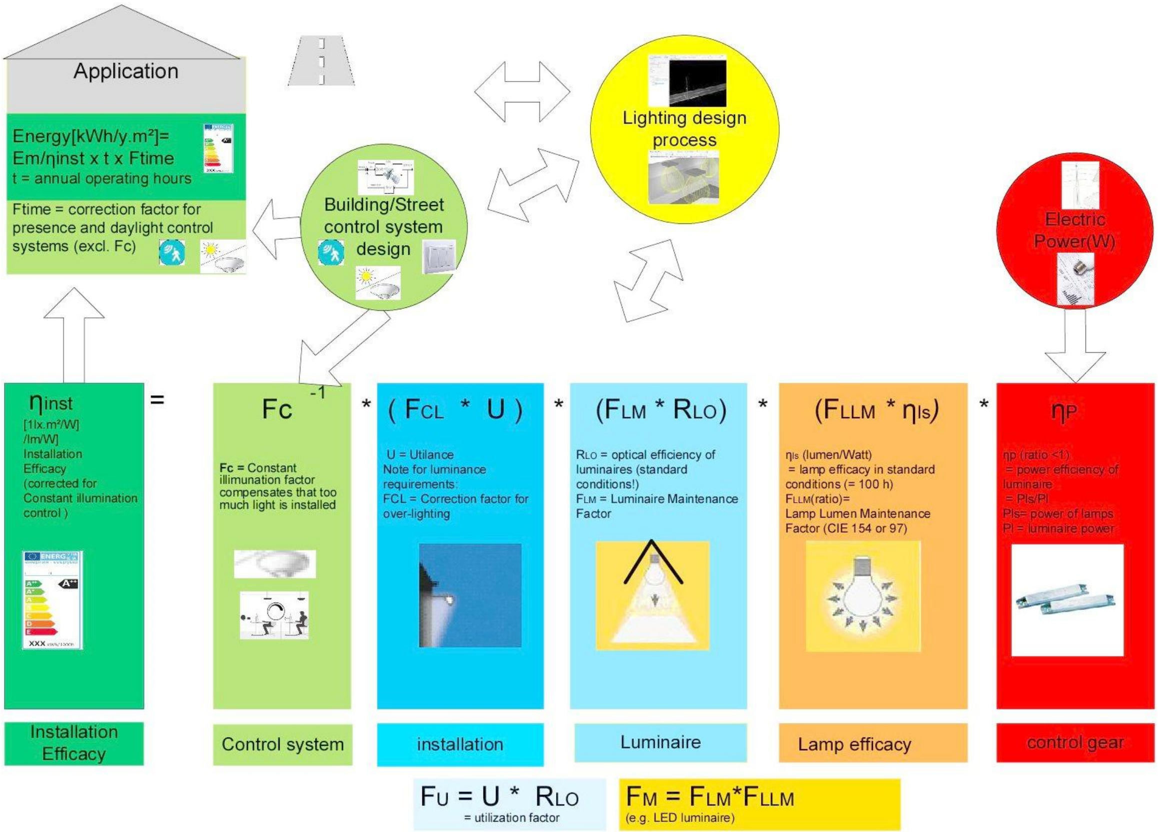

Figure 1-1: Components of a lighting system and the most relevant performance parameters related to energy efficiency

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[18] 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, a lighting system means a system of devices intended to deliver effective lighting to create a comfortable, functional and safe environment for human habitation, travel, work and leisure activities. In this study lamps luminaires, controls are only components of a larger system.. 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 for public outdoor lighting in Figure 1-2 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 (Uo) and colour rendering index (Ra). For street lighting similar requirements are defined in EN 13201 standards series.

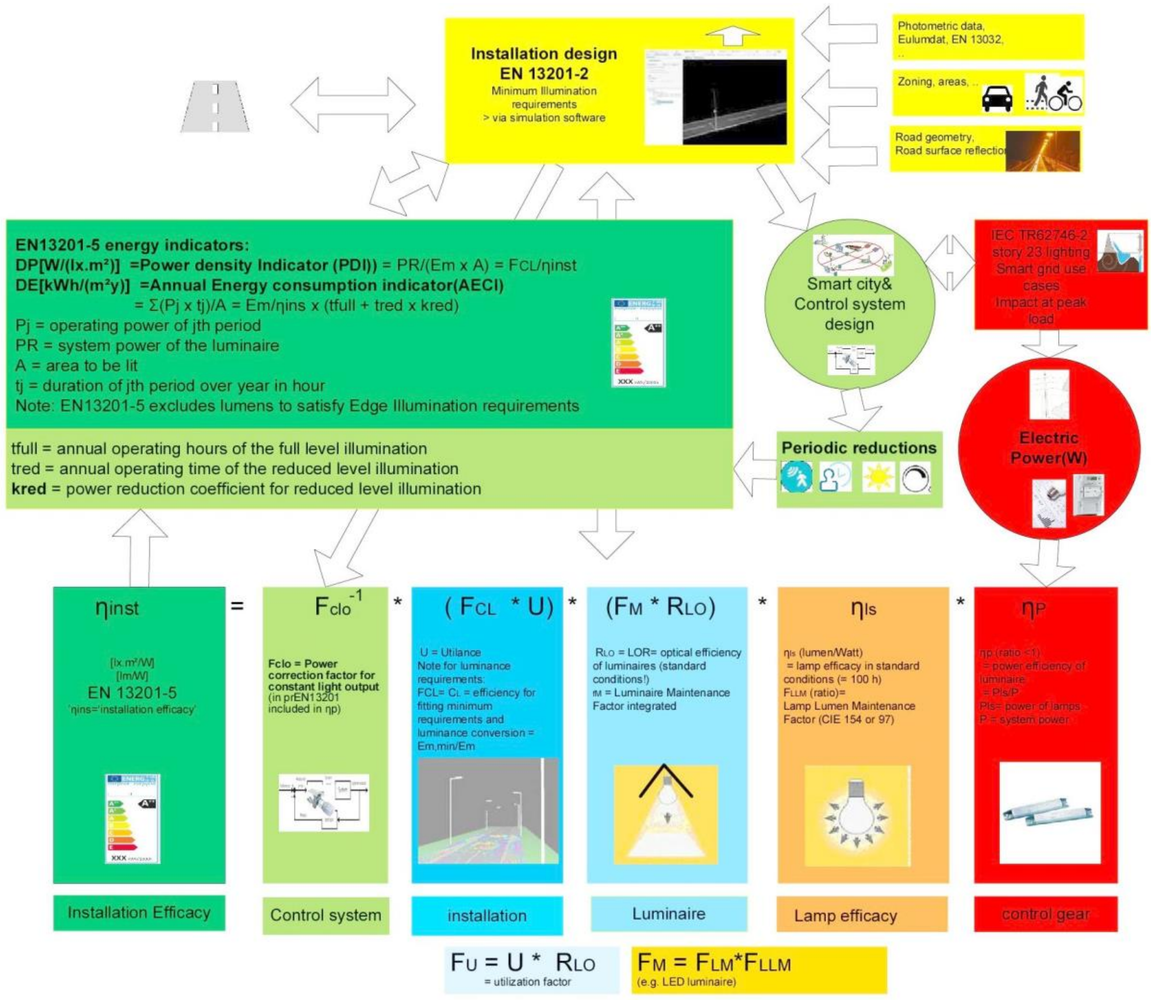

Figure 1-2: Context of public outdoor lighting systems with related standards and methods

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.

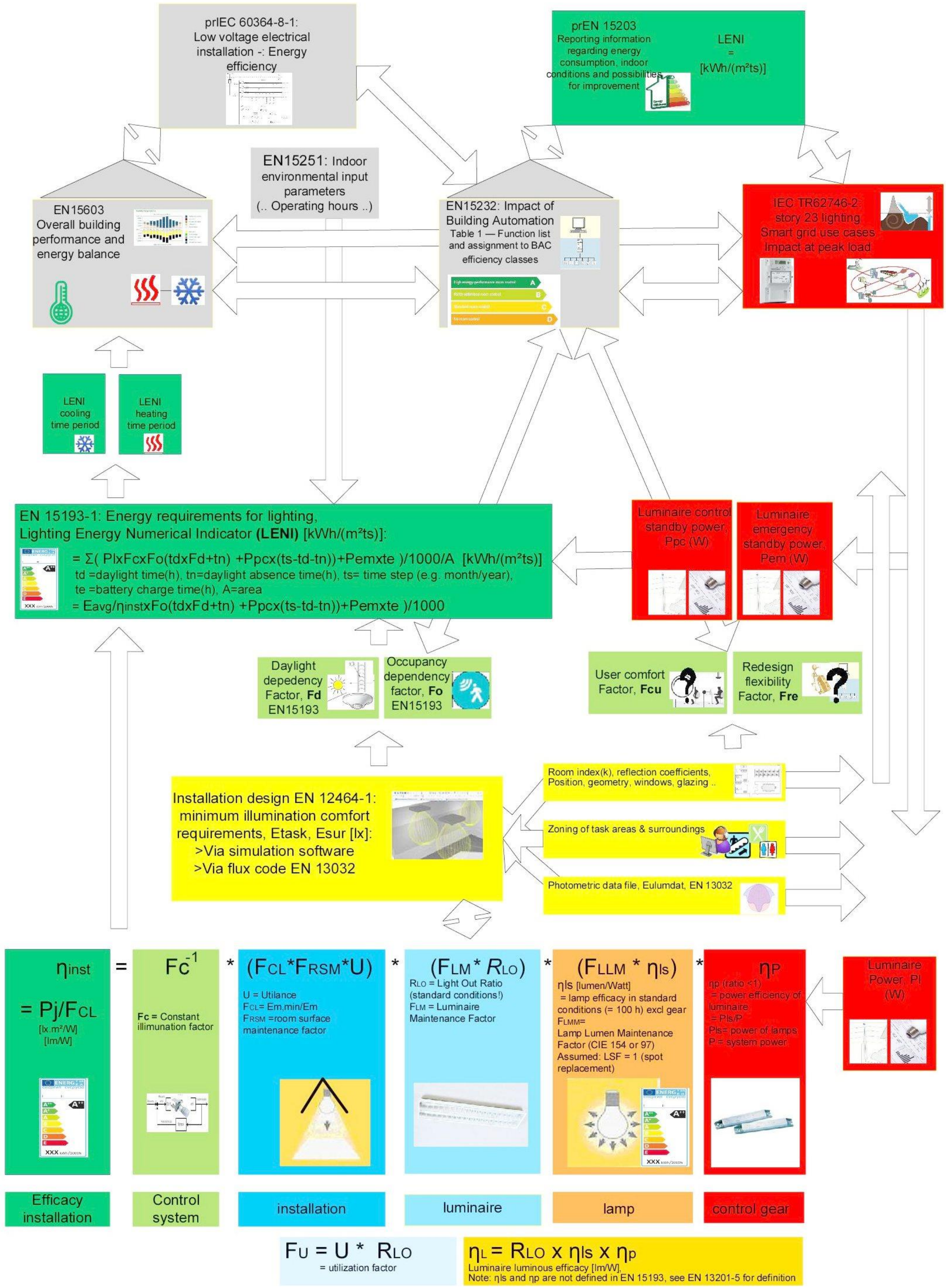

Figure 1-3: Context of indoor lighting systems for work places with related standards and methods

For defining a scope it is important to keep in mind that later on in Tasks 5&6 a life cycle assessment (LCA) will be done and that it will be necessary to compare improvement options, therefore a definition of a so-called functional unit will be needed. In standard ISO 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 in this study 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 domestic lighting systems with and without options for improvement. Therefore the proposed scope hereafter aims already to form a consistent category and some lighting systems with different functional criteria might be excluded.

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 is based on minimum measurable 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'[11]. These building parts will be taken into account in this study Task 3 being the system environment of the lighting system, see Task 3. Outdoor work place requirements are based on a different standard EN 12464-2 and are excluded because they have different functional requirements and they do not yet have a complementary standard defining their energy efficiency calculation. A consequent analysis in line with the ISO 14040 requirements is not obvious and might become complex and experimental without contributing to the proposed scope. On a similar ground also tunnel lighting will be excluded from this study, they are based on different local standards and/or the CEN CR 14380 technical report.

<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,

[11] http://erp4cables.net/

tablets, Christmas lighting chains, light art works, light art installations, etc.).
- Lighting systems designed for theatrical, stage, entertainment and similar applications.
- EN12464-1 does not provide definitive requirements for many commercial areas such as hospitality, museum and gallery, restaurants, high-end retail etc. Therefore they are also excluded.
- In general als 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[12] from previous eco-design legislation. Also excluded is the power use due to charging of batteries for emergency lighting.
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.

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 design and/or system technology is available for improvement.

<u>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)?</u>

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

12 http://ec.europa.eu/energy/en/topics/energy-efficient-products/lighting

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' according to the Ecodesign Directive, and installers and designers as their 'manufacturers'. 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:

The purpose of this task define lighting system categories for later analysis. Note that 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
- a maintenance plan
- 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' recommend 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. 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.
- 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.

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. Therefore roads can be classified according to their lighting classes for which requirements are defined in standard EN 13201-2 (2016). There are three main classes (M, C, P) and in each class several subclasses exists, e.g. M1 to M6. The standard contains the classes as described in the following sections.
The M classes are intended for drivers of motorized vehicles on traffic routes, and in some countries also residential roads, allowing medium to high driving speeds. The application of the subclasses depends on the geometry of the relevant area and on the traffic and time dependant circumstances. The appropriate lighting class has to be selected according to the function of the road, the design speed, the overall layout, the traffic volume, traffic composition, and the environmental conditions.
The lighting classes C are intended for use on conflict areas on traffic routes where the traffic composition is mainly motorised. Conflict areas occur wherever vehicle streams intersect each other or run into areas frequented by pedestrians, cyclists, or other road users. Areas showing a change in road geometry, such as a reduced number of lanes or a reduced lane or carriageway width, are also regarded as conflict areas. Their existence results in an increased potential for collisions between vehicles, between vehicles and pedestrians, cyclists and other road users, and/or between vehicles and fixed objects.
The lighting classes P are intended predominantly for pedestrian traffic and cyclists for use on footways and cycleways, and drivers of motorised vehicles at low speed on residential road, shoulder or parking lanes, and other road areas lying separately or along a carriageway of a traffic route or a residential road, etc.
In standard EN 13201-2(2016) more classes are described (e.g. HS, EV, G, D, SC), but technical report CEN/TR 13201-1(2014) does not give guidelines on the selection of these lighting classes. Optional G classes limit installed luminous intensity for the

restriction of disability glare and control of obtrusive lighting, D classes are for the restriction of discomfort glare and SC classes are based on semi-cylindrical illuminance for the purposes of improving facial recognition. EV classes are based on the vertical plane illuminance. The EV classes are intended as an additional class in situations where vertical surfaces need to be seen, e.g. at interchange areas. HS classes are an alternative to P classes and are based on hemispherical illuminance. The decision on whether these classes should be used for pedestrians and low speed areas is defined in the national road lighting policy.
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.

1.3.2.2 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 12665 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 12665) 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[13].

Occupancy 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.
- “Automatic On/off”(Type II), means the electric lighting is automatically switched off when the maintained illuminance is achieved by daylight at

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

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 occupancy sensors can be combined in one system and the function can be combined in the same sensor.
- These multi-sensors are very suitable for occupancy 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 occupancy 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.

Scene setting

In scene setting predefined light levels or switching patterns are programmed in the lighting control system. Scene controls or scene settings allow you to illuminate an area based on the lighting needs and ongoing activities.

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 (e.g. Dali, RF, ..).

Building or Lighting management system

Light and energy controls are integrated at the building level via building management systems.

Standard EN 15232 defines Building Management System (BMS) as: products, software, and engineering services for automatic controls (including interlocks), monitoring and optimisation, human intervention, and management to achieve energy-efficient, economical, and safe operation of building services equipment.

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
- occupancy detection
- individual control
- limitation of the peak output.

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

Simple daylight and time responsive on/off or on/dim/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).In On/dim/off controls the lighting is automatically dimmed to a set percentage based around a nominal midnight (midway between on and off).

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, the quality of photometric file provided by manufacturers and the surfaces within the model.

The selected light sources are characterised 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).

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[14] and follows with the modern technology of XML type[15] 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[16]

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.

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 must be recalculated from each new angle. Additionally, raytracing can be a slow process, especially if the model contains a large quantity of surfaces.

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

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. Lighting control systems can also be part of a broader building management systems and their communication system.

Examples of wired lighting communication systems are:

- DALI[17] (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.

Examples of building management systems are:

- KNX (standard EN 50090 series)
- LON (standard EN 14908)
- BACNET(standard ISO 16484-5).

1.3.2.6 Retrofittable components for luminaires

See preparatory study on light sources[18] 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.

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

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.h/m²]

Notes:

- 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.
- Energy savings from control systems will be modelled taking into account the time of use as secondary a parameter. In this context it is possible that during a certain period functional requirements are lower compared to the base line, e.g. with dimming systems.
- For road lighting where luminance($\bar{L}m$) is used instead of illuminance (Em), the following conversion formula can be used(see also EN 13201-5), assuming a reference asphalt reflection coefficient:

$$Em,min = \bar{L}m,min/0.07$$

- 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):

$$Em,min = Ehs/0.65$$

where:

Em,min is the minimum average maintained illuminance of the functional unit
$\bar{L}m$,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)[19]

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

[19] 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

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:

- **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 12464-1 or EN 13201-2;
- **Semi-cylindrical illuminance, Esc [1 lx]**
  total luminous flux falling on the curved surface of a very small semi cylinder divided by the curved surface area of the semi cylinder. The purpose is to Identify faces at a distance. To permit this, semi-cylindrical illuminance needs to be at least 1 lux. Measurements are taken 1.5 metres above the ground. Semi-cylindrical illuminance for facial recognition can be a supplementary requirement to horizontal illuminance;
- **Hemispherical illuminance, Ehs [1 lx**]
  luminous flux on a small hemisphere with a horizontal base divided by the surface area of the hemisphere. Hemispherical illuminance is mainly used in road lighting in Denmark but seldom in other countries;
- **Maintained luminance, $\bar{L}$m [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;
- **Overall illuminance uniformity, Uo**
  Ratio of minimum illuminance to average illuminance on a surface, for example as specified in EN 12464 or 13201;
- **Longitudinal uniformity, Ul**
  lowest of the ratios determined for each driving lane of the carriageway as the ratio of the lowest to the highest road surface luminance found in a line in the centre along the driving lane. This parameter is used in road lighting;
- **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);
- **Edge illuminance ratio EIR (of illumination of a strip adjacent to the carriageway of a road), REI**
  average horizontal illuminance on a strip just outside the edge of a carriageway in proportion to the average horizontal illuminance on a strip inside the edge, where the strips have the width of one driving lane of the carriageway;
- **The colour related parameters are discussed with the light sources**
- **Recommended reflectances of surfaces in indoor lighting**
- **Others can be defined in task 3.**

In lighting the primary design parameter for specification and optimisation is most often the minimum horizontal maintained illuminance of the task or surrounding area, see EN 12464-1. The other secondary design parameters are then treated as complementary limit values used for design verification. In some cases the primary design requirements can be vertical illuminance, e.g. for storage racks, or in road lighting also maintained luminance [Cd/m²]. In indoor lighting it is also possible to specify apart from horizontal task area illuminance requirements complementary illuminance requirements for wall and ceiling. For example, specify the average wall illuminance above the working plane (≥ 50%) and the ceiling (≥30%) to avoid a dark or gloomy effect.The previous parameters are the common parameters for specifying functional indoor and road lighting according to EN 12464-1 or EN 13201-5. However, for other applications such as ambient lighting in shops or houses they are insufficient quality parameters. For these lighting design applications commonly accepted design metrics do not exist. Therefore amongst others these applications were excluded previously.

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 EN 13201-5.
- **Installation luminous efficacy , η_{inst} [lm/W]**
  The quotient of the functional lumen needed to satisfy the minimum illumination requirements versus the input power(Annex B, EN 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 13201-5 (unit: $W.lx^{-1}.m^2$ or W/lm). Note this is and the reverse value of installation luminous efficacy (D_p = $=C_L/\eta_{inst}$).

Important secondary control gear parameters are:

- **Maximum luminaire power, P_l [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 η_p**
  ratio between power of lamp(s) and the maximum luminaire power (Annex B, EN13201-5);
- **Ballast or Driver Reliability, 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;
- **Lifetime**
  A statistical measure (or estimate) of how long a product is expected to

perform its intended functions under a specific set of environmental, electrical and mechanical conditions. Lifetime specifications can only describe the behavior of a population; any single product may fail before or after the rated lifetime;

- **Mean Time Between Failures (MTBF) (MIL-HDBK-217)**
  The average time between failures during useful life for repairable or redundant systems. This is valid and useful if the failure rate may be assumed constant over time, hence in the normal life of a product excluding the infant mortality[20] and end-of-life wear out. In this case for example a driver MTBF of 100,000 hours means that over a 10-year (continuous) useful life period, 87.6% of the units will likely fail[21] and need to be replaced.

Important lamp/light source parameters are:

- **Luminous efficacy of a light source or luminaire used in the installation, η_{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). In case of luminaires, the luminous flux emitted at luminaire level and not at light source;
- **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. LED modules lose some of their luminance over their service life. This process (known as degradation) is denoted by Lx;
- **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_{14}.);
- **Chromaticity coordinates**
  Coordinates which characterise a colour stimulus (e.g. a lamp) by a

[20] Impact from infant mortality can be reduced by submitting each products to a burn in test prior to commissioning.
[21] Assuming an equal failure distribution over time.

ratio of each set of tristimulus values[22] 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);

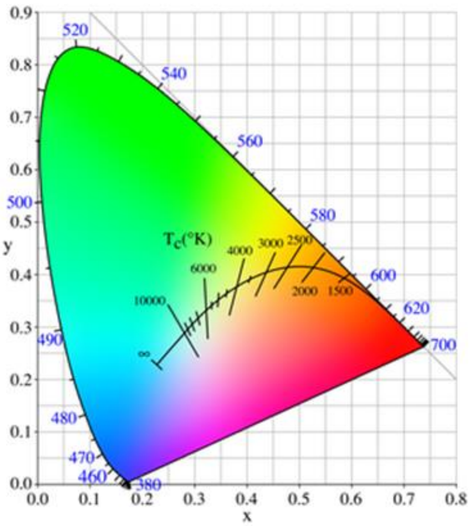

Figure 1-5: The CIE 1931 x,y chromaticity space, also showing the chromaticities of black-body light sources of various colour temperatures (Tc), and lines of constant correlated colour temperature (Tcp).

- **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[23];
- **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;

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

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

[22] 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.
[23] CIE 15: 2004 Colorimetry, 3rd ed.

- **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);

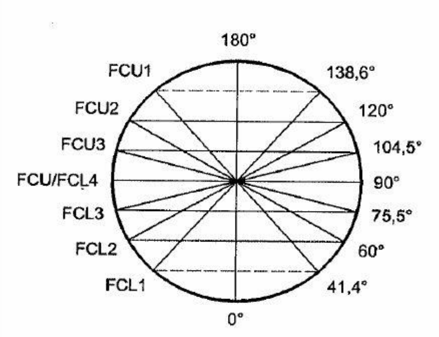

Figure 1-6: Zones for the calculation of accumulated luminous fluxes according to the CEN flux-code.

- **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);

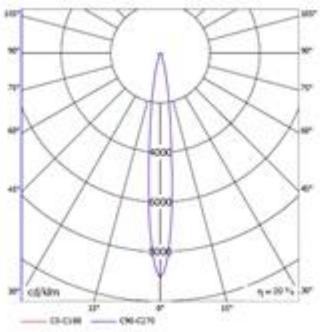

Figure 1-7: Example of a polar intensity curve

- **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.

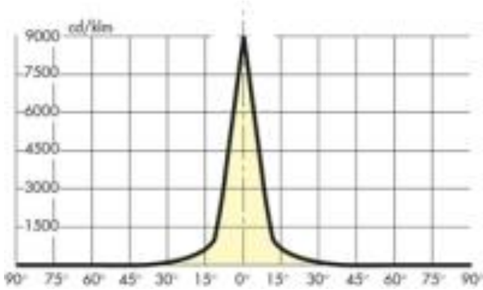

Figure 1-8: Example of a Cartesian light distribution diagram

- **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;

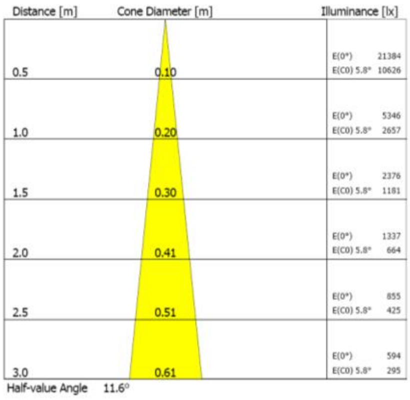

Figure 1-9: Example of an Illuminance Cone Diagram

- **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, FLM**
  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 (IEC 62717). LED modules lose some of their luminance over their service life. This process (known as degradation) is denoted by Lx.;
- **LED luminaire gradual failure fraction, LxBy** (IEC 62717)
  The percentage(y of By) of LED luminaires that fall below the target luminous flux of x percent (x of Lx) at the end of their designated life. Gradual lumen loss refers to the product considered LED luminaire or LED module and can occur as a result of a gradual decline in luminous flux or the abrupt failure of individual LEDs on the module. The By value is directly dependent on the L value and denotes how many modules (in per cent) are permitted to fall short of the Lx value;
- **LED luminaire catastrophic failure rate or abrubt failure fraction, LxCz** (IEC 62717)
  The percentage(z of Cz) of LED luminaires that have failed completely by the end of rated life (x of Lx). For example, when 0.2% of all LED modules will fail per 1,000 hours, it means that no more than 10% of all modules are permitted to fail after 50,000 hours.;

- **LED luminaire failure fraction, LxFy** (IEC 62717)
  at their rated life designates the percentage (fraction) of failures. It is a combination of By and Cz. This specification is mainly used in integrated LED lamps for the residential market, in the professional market more often both LxBy and LxCz are used;
- **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, FU**
  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). See also definition of Utilance;
- **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. The reference surface in indoor lighting (EN 12464-1) is usually the horizontal floor area. In road lighting it is the road surface and the edge can be included or excluded. In this study the edge will be excluded in line with the PDI parameter defined in EN 13201-5. Note that the Utilance is an indicative parameter only for optimising towards providing the horizontal illuminance while also other design criteria are involved that can limit the optimisation, see therefore Task 4.;
- **Useful Utilance for a reference surface, UU**
  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, CL (EN13201-5) or FCL** (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;
- **Room surface maintenance factor, FRSM**
  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,room/road geometry, zoning of the task area, time of use, daylight factor, etc... 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.

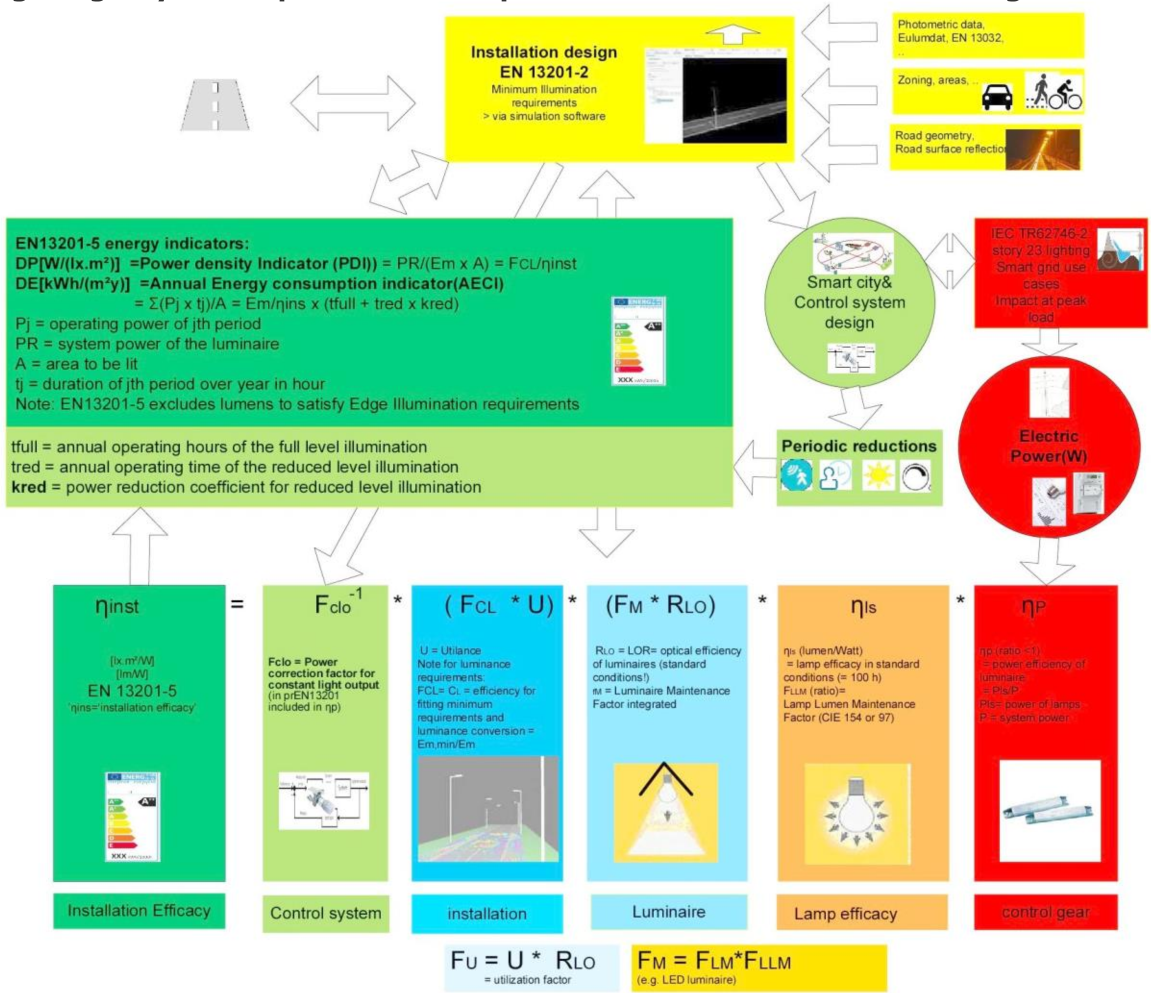

Figure 1-2 **contains the formulas for road lighting and Figure** 1-3 **for indoor lighting.Examples of other important performance parameters are:**

- **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[24] 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**

[24] 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).

- **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 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 Harmonised 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[25] 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 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.

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

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'[26] 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.

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

Input received from IALD[27]:

“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’[28] 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

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

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 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.

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[27]:
"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.

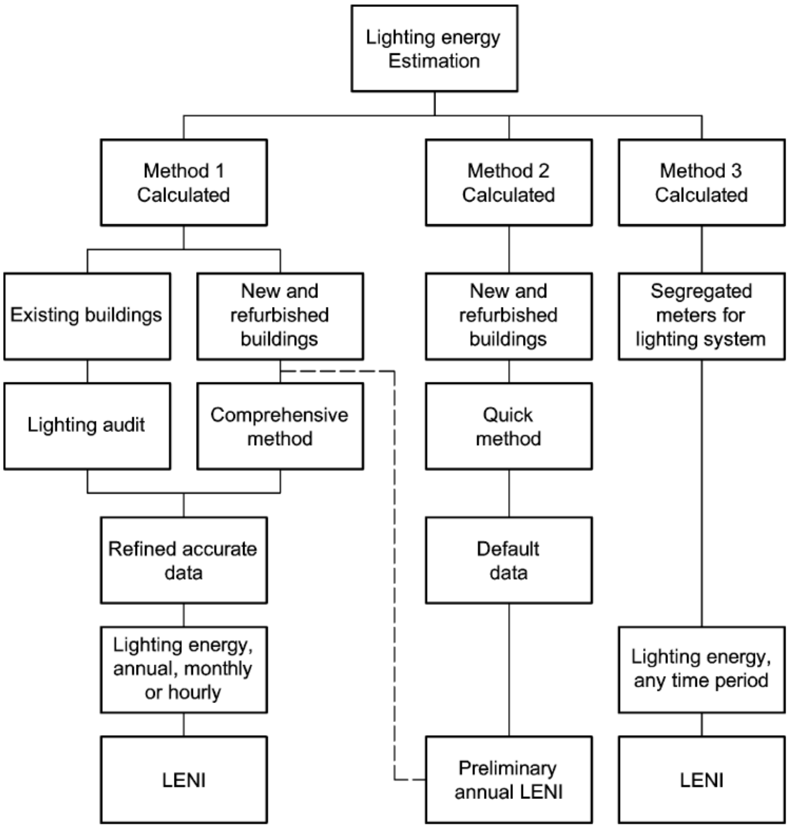

Figure 1-10: Flow chart illustrating alternative routes to determine energy use in prEN 15193-1

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..

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

prEN15193-1&2:2016 is currently (11/2016) presented for voting to the CEN members. The draft version (6/2016) presented for vote was used in Task 3&4. It is up to date for the purpose of this study. In the future there is still margin for improving the measurement methods, which is currentlt very basic, but therefore more research should be done. Note that within this voting procedure still some changes can occur.

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

.

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. 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: - sport facilities - storage - industrial buildings - etc.		1		

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

Gaps in EN 15232:2007 :

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 15232:2007 is ongoing and the following comment on this process was received from EU.BAC[29] 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[30], web-lights, PoE[31]) should be considered when updating EN 15232;

[29] http://www.eubac.org/
[30] http://www.knx.org/knx-en/index.php
[31] 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.
- It is likely that the gaps mentioned before related to lighting systems in version EN 15232:2007 will remain in the current update(2016), due to a lack of resources and available data for this.

EN 13201-5:2016 'Road lighting-Part 5: Energy performance indicators.'

Scope:
The purpose of this standard is to define energy performance indicators for road lighting installations. The standard introduces two metrics, the power density indicator (PDI) *D*P and the annual energy consumption indicator (AECI) *D*E that should always be used together. In addition, the installation luminous efficacy (*η*inst) can be used for comparing the energy performances of alternative road lighting installations.

.

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 D_E also dimming is taken into account.
>
> The Power density Indicator (D_P) 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 D_E nor D_P 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.

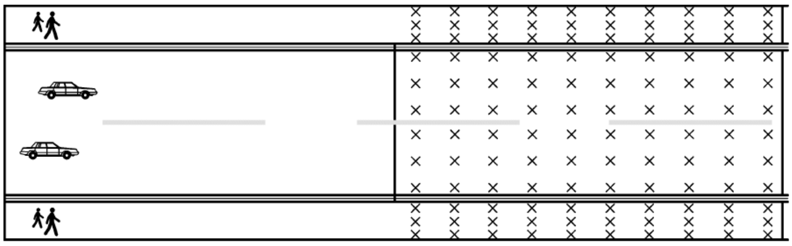

Figure 1-14: Example of Annex A for Road and two sidewalks in both sides

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

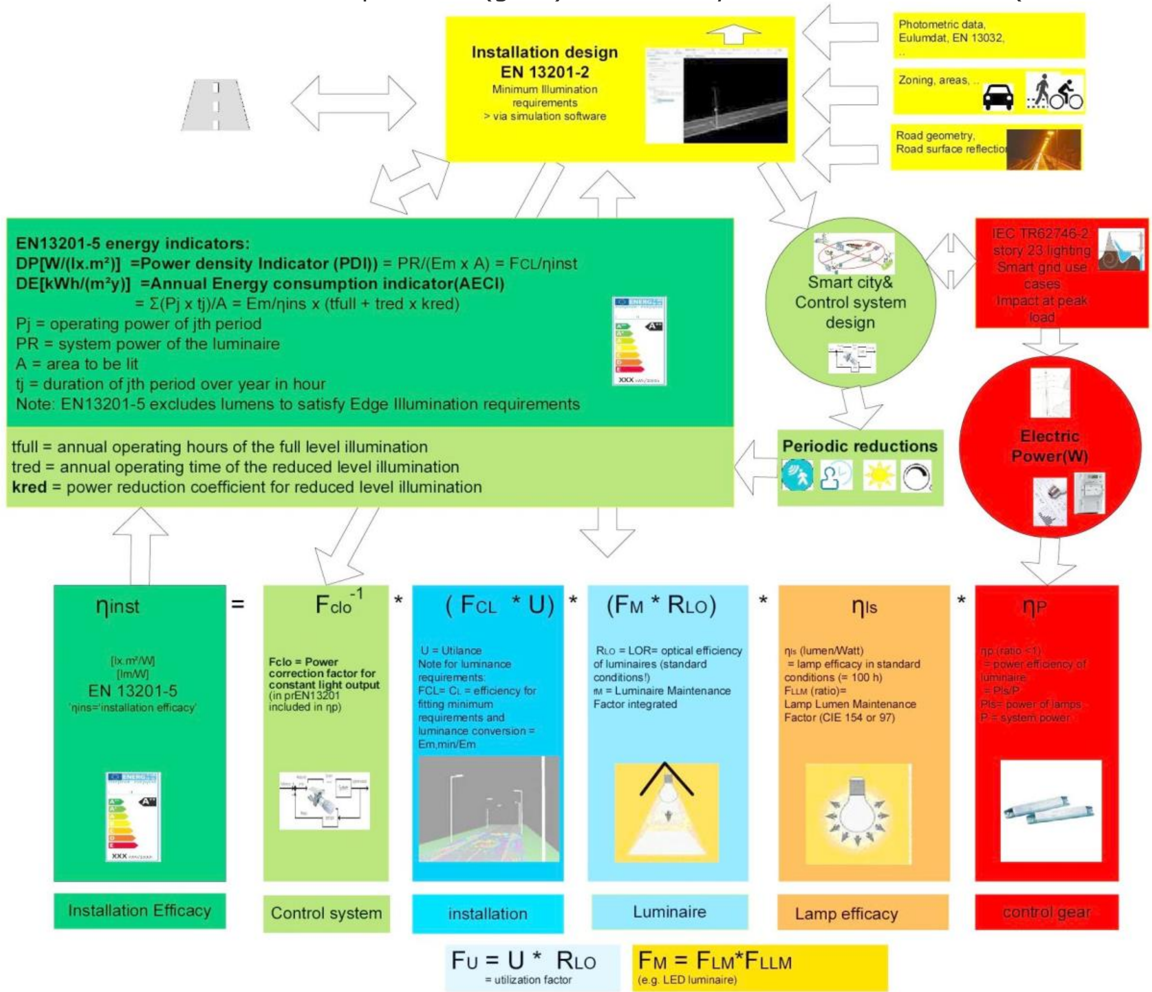

Figure 1-2) is identical to the system component defined in this study (see Figure 1-1).
Therefore Annex B defines the 'installation luminous efficacy' (η_{inst}) which takes over-lighting into account, the formula and related parameters are:

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

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.

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.

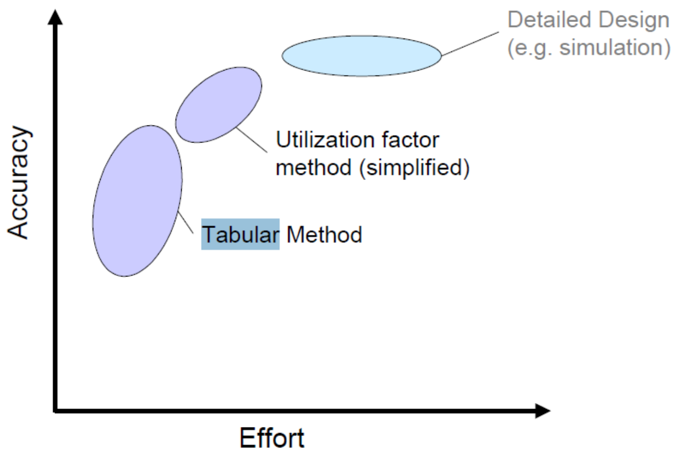

Figure 1-16: Possible different methods to obtain the installed, electric power

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). However it should be noted that the existing point source model is adequate for most applications.

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. It is a simplified method and should be noted that it only address zones where light is designed to spread uniformly across a plane parallel to the floor of a room.

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[32].

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

[32] 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. • R_a and UGR similar to adjacent areas. • 150 lx if there are vehicles on the route. • 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. • 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.

Section 4.6 specifies particular minimum illuminances on wall and ceilings. There are also targets for cylindrical illuminance specifically in areas where visual communication is crucial, e.g. a meeting room. It should be noted that therefore additional energy might be required.

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[27] 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[33].

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.

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

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 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.

IEC/TR 63037 'Electrical interface specification for self ballasted lamps and controlgear in phase cut dimmed lighting systems’

Scope:

This Standard is a standard under development to organize the compatibility of self ballasted lamps, such as LED retrofit lamps, with phase cut dimmers.

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[34]

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[35] 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.

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[34] 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

[35] 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

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.

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[36]. 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.

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

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 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

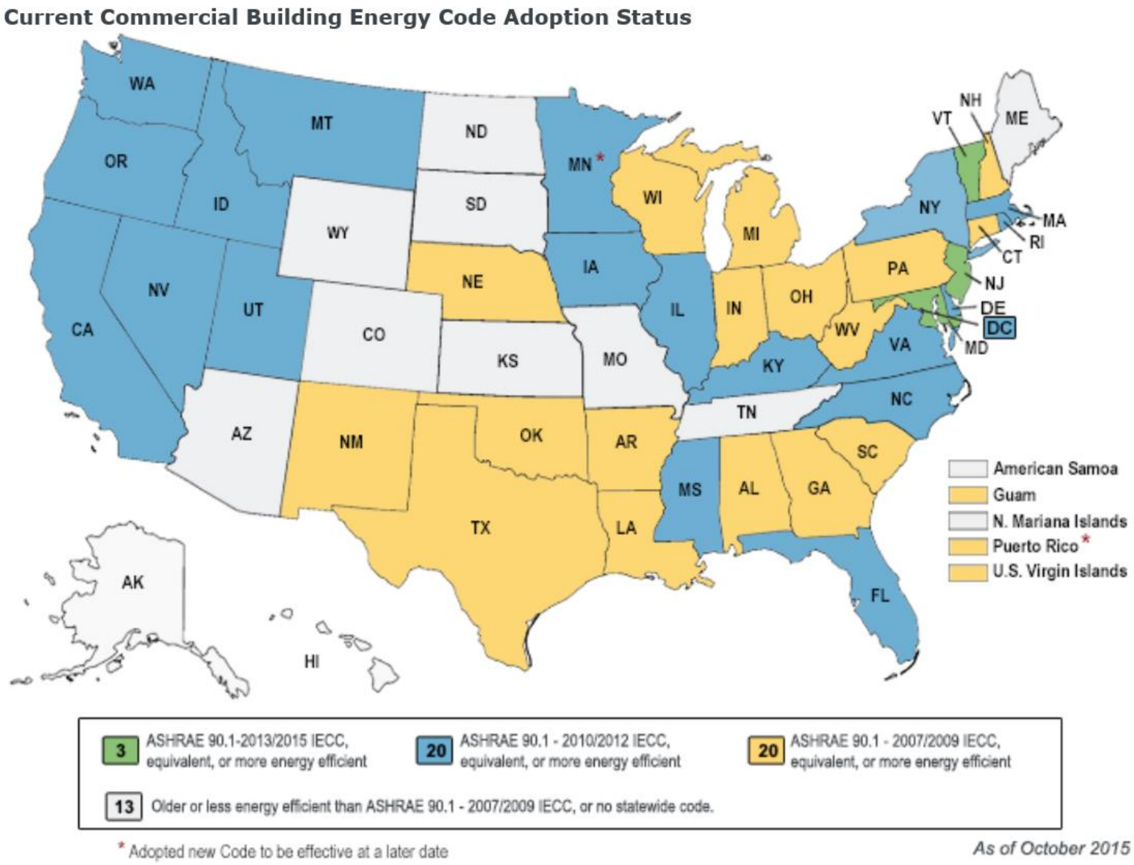

Figure 1-19: The status of building energy codes adopted for commercial buildings in US states

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).

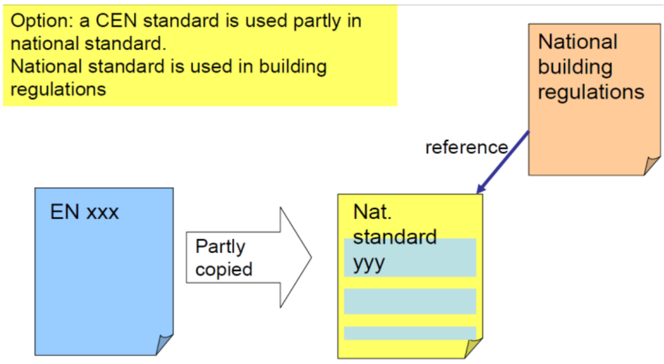

Figure 1-20: Actual situation in many EU Member States regarding how they use the EPBD standards[37]

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)[38].

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.

[37] 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).
[38] https://www.cen.eu/work/supportLegislation/Mandates/Pages/default.aspx

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.
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[39] 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[39] 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

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

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 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.

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 Ecodesign Directive (ED)
- The Energy Labelling Directive (ELD)
- The Energy Performance in Buildings Directive (EPBD)
- The Energy Efficiency Directive (EED)

Implementing regulations within the ED 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)

<table>
<tr><th>Directive</th><th colspan="8">Measure</th></tr>
<tr><td>EPBD</td><td colspan="5">Building Energy Performance Codes</td><td colspan="2">EPCs</td><td>Incentives (Article 10(2))</td></tr>
<tr><td>Scope</td><td>New build</td><td>Existing buildings</td><td>Residential</td><td>Non-residential</td><td>Cost optimal assessment (Article 5)</td><td>Residential</td><td>Non-residential</td><td>All buildings</td></tr>
<tr><td>Status</td><td>In most MS codes the LS is not treated in a prescriptive manner but only indirectly.

BACS mostly not treated explicitly.</td><td>In most MS codes the LS is not treated in a prescriptive manner but only indirectly.

Mixed, BACS mostly not treated explicitly.</td><td>In most MS codes the LS is not treated in a prescriptive manner but only indirectly.

Mixed, BACS mostly not treated explicitly.</td><td>In most MS codes the LS is not treated in a prescriptive manner but only indirectly.

Mixed, BACS mostly not treated explicitly.</td><td>LS are included.

BACS are mostly not assessed explicitly, if at all.</td><td>LS are part of whole building rating.

No evidence any MS has considered applying this article to BACS explicitly.</td><td>LS are part of whole building rating.

No evidence any MS has considered applying this article to BACS explicitly.</td><td>No evidence any MS has considered applying this article to LS or BACS explicitly.</td></tr>
<tr><td>ECODESIGN/LABELLING</td><td>MEPS</td><td>Classification/ Labelling</td><td>Other requirements</td><td colspan="5" rowspan="2"></td></tr>
<tr><td>Status</td><td>LS being considered in Lot 8/9/19 review study (http://ecodesign-lightsources.eu/) Further consulation process ongoing.

Household lamps in regulations 244/2009, 859/2009 and 874/2012. Directional lighting in regulations 1194/2012 and 874/2012</td><td>LS being considered in Lot 8/9/19 review study (http://ecodesign-lightsources.eu/) .Further consulation process ongoing

Household lamps in regulations 244/2009, 859/2009 and 874/2012. Directional lighting in regulations 1194/2012 and 874/2012

Tertiary sector lamps and ballasts in</td><td>LS LS being considered in Lot 8/9/19 review study (http://ecodesign-lightsources.eu/), Further consulation process ongoing

BACS under consideration for possible inclusion in work plan</td></tr>
</table>

	Tertiary sector lamps and ballasts in regulation 245/2009 and 347/2010 Light sources being considered in Lot 8/9/19. BACS included in 2016-19 work plan	regulation 245/2009 and 347/2010 Light sources being considered in Lot 8/9/19. BACS included in 2016-19 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 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 18th 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 1st of September 2009, 2010, 2011 and 2012, eliminate low-efficacy ('incandescent') lamps in subsequently lower lumen output-levels[40]. 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

[40] '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[41]. As it stands today, Stage 6 requires that instead of the maximum rated power P_{max} (in W) being 0.8·(0.88√Φ+0.049Φ), 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·(0.88√Φ+0.049Φ). 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)

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.

Please note that that a parallel study on light sources for reviewing this regulation has been concluded[42] and for the latest state of play consult the website of the EC[43].

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 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;

[41] VHK, Review study on the stage 6 requirements of Commission Regulation (EC) No 244/2009, draft report for the European Commission, April 2013.
[42] http://ecodesign-lightsources.eu/documents
[43] https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products

  - 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);
    - 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)

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.

This regulation is amending Commission Regulation (EC) No 245/2009, 'in order to avoid unintended impacts on the availability and performance of the products covered by that Regulation'. The amendments also intend to 'improve coherence, as regards the requirements on product information between Regulations 244/2009 and 245/2009'. Regulation 347/2010 introduces some changes in the exemptions and a large number of changes to the tables in Annex III of 245/2009 on minimum CFLni lamp efficacy and lamp lumen maintenance and survival factors (FLLM, FLS) for HPS lamps for stage 2 in 2012.

Please note that that a parallel study on light sources for reviewing this regulation has been concluded[44] and for the latest state of play consult the website of the EC[45].

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[46]);
- colour consistency (maximum variation of chromaticity coordinates within a six-step MacAdam ellipse[47] or less);

44 http://ecodesign-lightsources.eu/documents
45 https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products
46 In accordance with point 3.1.3 (l) of Annex III of commission regulation 1194/2012
47 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

- 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[48]);
- lumen maintenance (>80% at 6000h).

Please note that that a parallel study on light sources for reviewing this regulation has been concluded and for the latest state of play consult the website of the EC .

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)

Please note that the current label system is under review. On 15 July 2015 the Commission proposed a return to a single A to G label scale[49] and new labels were proposed in the light source study[50].

1.5.1.6 Energy performance of buildings Directive

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

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:

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describing acceptable colour deviation between LED lamps/luminaires of the same model (1 step=1 ellipse area; 2step=2 concatenated ellipse areas, etc.)

[48] 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.

[49] https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products

[50] http://ecodesign-lightsources.eu/documents

- 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.

Ongoing review:
On the 30 November 2016 the Commission proposed an update to the Energy Performance of Buildings Directive to help promote the use of smart technology in buildings and to streamline the existing rules[51]. The Commission also published a new buildings database – the EU Building Stock Observatory – to track the energy performance of buildings across Europe.
Under the existing Energy Performance of Buildings Directive:

- energy performance certificates are to be included in all advertisements for the sale or rental of buildings
- EU countries must establish inspection schemes for heating and air conditioning systems or put in place measures with equivalent effect
- all new buildings must be nearly zero energy buildings by 31 December 2020 (public buildings by 31 December 2018)
- EU countries must set minimum energy performance requirements for new buildings, for the major renovation of buildings and for the replacement or retrofit of building elements (heating and cooling systems, roofs, walls, etc.)
- EU countries have to draw up lists of national financial measures to improve the energy efficiency of buildings

Under the Energy Efficiency Directive:

- EU countries make energy efficient renovations to at least 3% of buildings owned and occupied by central government
- EU governments should only purchase buildings which are highly energy efficient
- EU countries must draw-up long-term national building renovation strategies which can be included in their National Energy Efficiency Action Plans

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

[51] https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings

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[52]:

- 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 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)[53].

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

[52] Implementing the Energy Performance of Buildings Directive (EPBD) – Featuring Country Reports 2012
[53] Implementing the Energy Performance of Buildings Directive (EPBD) – Featuring Country Reports 2010, '3.1.5 Processes for making recommendations'

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 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[54].

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)[55]. 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.'.

[54] 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'
[55] 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

The EPBD recast also explicitly formulates that 'Member States should use, where available and appropriate, harmonised instruments, in particular testing and calculation methods and energy efficiency classes developed under measures implementing Directive 2009/125/EC'.[56]

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[57]. 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[58]. 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[59] .

In the Flemish region there are also specific system requirements[60] 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[61] 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[62] 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:

[56] Recital (12) of the EPBD recast.
[57] Implementing the Energy Performance of Buildings Directive (EPBD) - Featuring Country Reports 2012, ISBN 978-972-8646-28-8.
[58] http://www2.vlaanderen.be/economie/energiesparen/epb/doc/BijlageEPU20130719vergunningenNA2014.pdf
[59] http://www.energiesparen.be/epb/prof/software
[60] http://www.energiesparen.be/epb/eiseninstallaties
[61] http://www.rt-batiment.fr/batiments-neufs/reglementation-thermique-2012/textes-de-references.html
[62] http://www.rt-batiment.fr/batiments-neufs/reglementation-thermique-2012/logiciels-dapplication.html

- 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;
- 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[63] 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) 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 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: • 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 • standard fittings supplied with low energy lamps with integrated control gear (e.g. bayonet or Edison screw base compact fluorescent lamps) Light fittings with GLS tungsten filament lamps or tungsten halogen lamps would not meet the standard. The Energy Savings Trust publication *GIL20 Low Energy*

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

		Domestic Lighting gives guidance on identifying suitable locations for fixed energy lighting. A single switch should normally operate no more than six light fittings with a maximum total load of 100 circuit-watts.
Fixed external lighting	Where fixed external lighting is installed, provide light fittings with the following characteristics: a. Either: I. lamp capacity not greater than 100 lamp-watts per light fitting, and II. all lamps automatically controlled so as to switch off after the area lit by the fitting becomes unoccupied, and III. all lamps automatically controlled so as to switch off when daylight is sufficient b. Or: I. lamp efficacy greater than 45 lumens per circuit-watt, and II. all lamps automatically controlled so as to switch off when daylight is sufficient, and 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**
		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 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.

Ongoing review:
On the 30 November 2016 the Commission proposed an update to the Energy Efficiency Directive[64], amongst others.

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

Directive 2002/95/EC of the European Parliament and of the Council

The RoHS Directive has been revised and now 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 revised RoHS Directive 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 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 on lighting systems

[64] https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings

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[65]. 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

[65] 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.

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*"[66].

Public authorities are major consumers in Europe: they spend approximately €2 trillion annually, equivalent to some 19% of the EU's gross domestic product[67]. 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[68]. 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[69], 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

[66] 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
[67] http://ec.europa.eu/environment/gpp/what_en.htm
[68] http://ec.europa.eu/environment/gpp/gpp_criteria_process.htm
[69] http://www.eco-lighting-project.eu/home

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[70] 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)[71].
At present the following lighting equipment is covered:

- 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[72]. 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. harmonised 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 harmonise 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

[70] http://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm
[71] http://ec.europa.eu/environment/gpp/gpp_criteria_wp.htm
[72] http://ec.europa.eu/environment/gpp/pdf/criteria/indoor_lighting.pdf

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[73]. Where harmonised standards are not available, existing national standards apply.

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[74].

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 harmonised 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

[73] http://ec.europa.eu/enterprise/newapproach/standardization/harmstds/reflist/construc.html
[74] http://ec.europa.eu/enterprise/construction/index_en.htm

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.

"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". [75]

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[76] in Switzerland

[75] REGULATION (EU) No 305/2011, Article 3
[76] http://www.minergie.ch/leuchten.html

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

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[78]' 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.

[77] http://www.milieukoopwijzer.be/criteria/armaturen
[78] http://www.enob.info/de/software-und-tools/projekt/details/tek-teilenergiekennwerte-fuer-nichtwohngebaeude-im-bestand/

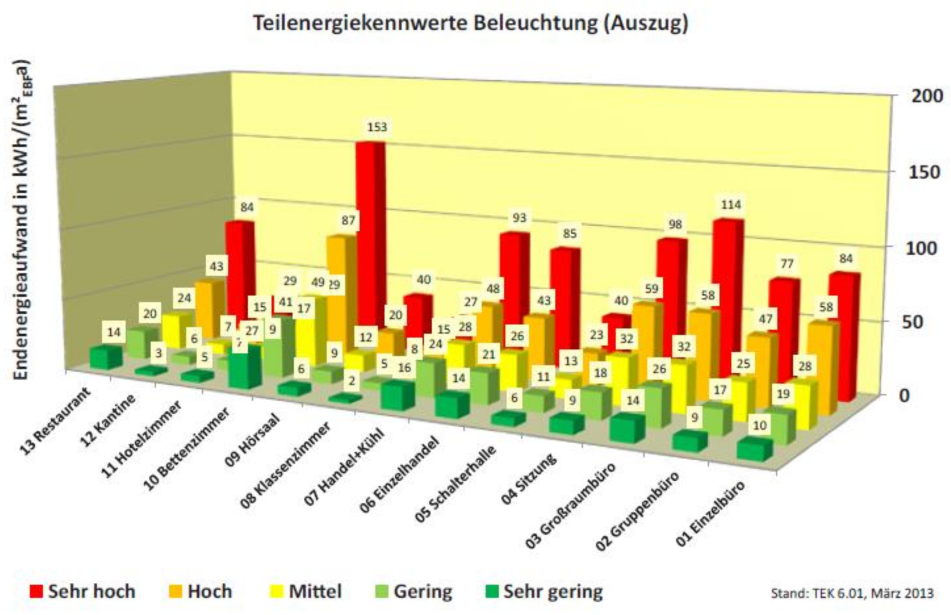

Figure 1-21: Reference values in kWh/y.m² for lighting in various applications (source: IWU TEK Tool[79]).

LEED (Leadership in Energy and Environmental Design)

LEED[80] 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 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)

[79] IWU (2014): 'Teilenergiekennwerte Neue Wege in der Energieanalyse von Nichtwohngebäuden im Bestand', ISBN: 978-3-941140-38-7

[80] http://www.usgbc.org/leed

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

SPACE	MAXIMUM ILLUMINATION POWER DENSITY
(W/m2)	
Auditorium, church and public hall	10
Boardroom and conference room	10
Carpark – general	6
Carpark – entry zone (first 20m 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
Lounge area for communal use in a Class 3 building or Class 9c	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 lot to an ambient level of less than 200 lx	7
Plant room	5

ILLUMINATION POWER DENSITY ADJUSTMENT FACTORS

Where rooms have particular control devices such as a manual dimming system or a motion detector, special considerations are allowed when calculating your w/m2.

Adjustment Factors apply only to luminaires controlled by a particular control device.

You can divide your total w/m2 for a room by the adjustment factor given for a control system.

This can help reduce your w/m2 and potentially reach compliance.

Lighting Timer	Corridor Only	0.7
Motion detector	At least 75% of space is controlled by this device	0.9
	Area less than 200m2 is switched as a block by one or more detectors	
	Up to 6 lights are switched as a block by one or more detectors.	0.7
	Up to 2 lights are switched as a block by one or more detectors.	0.55
Manual dimming system. Not including Class 2 and Class 4	Where at least 75% of the space is controlled by a manual dimmer	0.95
(Class 2 and Class 4 only)	Where at least 75% of the space is controlled by a manual dimmer	0.85
Programmable dimming system (DALI)	Where at least 75% of the space is controlled by programmable	0.85
Dynamic Dimming	Automatic compensation for Lumen depreciation. Fluorescent: High Pressure Discharge:	 0.9 0.8
Fixed Dimmer	Where at least 75% of the area Is controlled by a fixed dimmer % of full power of which the dimmer is set, divided by:	0.95
Daylight sensor	Lights within space adjacent to windows (not roof lights)	0.5
	Lights within space adjacent to roof lights	0.5

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 2015.

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		
Space	LENI (kWh/m^2)	LPD (W/m^2)	tli [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

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 further price information will also be supplied in Task 4.

Note: this is not a complete study because MEErP Tasks 5&6 are not included, but some market data for these tasks is already included.

Summary of task 2:

A lighting system somehow differs from other products examined in ecodesign preparatory studies as it is designed in advance but 'assembled in situ' rather than produced, imported or exported as a whole. Consequently lighting systems are not distinguished as traded products in the Eurostat Prodcom statistics. Such data are available for some of the lighting system components such as light sources, control gears, luminaires and some lighting controls, and these data are reported in this chapter.

In the absence of direct market data it is nevertheless possible to estimate the energy savings due to lighting system improvements by linking the Task 7 scenario analysis to the 'Model for European Light Sources Analysis' (MELISA), that has been developed in the Ecodesign preparatory study on Light Sources. A complication is that MELISA data all refer to light sources and not to luminaires or to buildings or spaces to be illuminated, which is the focus of the Lighting Systems study. To circumvent this problem, reference will be made to the total sold and installed luminous flux of MELISA and to the total full-power equivalent annual operating hours.

Two factors will be used to model the influence of lighting system improvements in MELISA:

- The Flux Factor F_{phi}, representing the reduction in installed luminous flux (at light source level) due to optimisation of lighting system designs (layout of luminaires, possibly reduction of the number of luminaires, use of luminaires with higher efficacy),
- The Hour Factor F_{hour}, representing the reduction in annual full-power equivalent operating hours due to the introduction of lighting controls (dimming or switching of lights in function of daylight availability, room occupancy, lumen degradation with time).

MELISA already includes energy savings due to improvements in light source efficacy. Linking the Systems analysis to MELISA using only the factors F_{phi} and F_{hour} avoids double counting of these savings.

In general, the factors F_{phi} and F_{hour} will differ between reference cases (e.g. different optimisation possibilities for offices, corridors, manufacturing halls, warehouses, shops, motorways, secondary roads, roads in residential quarters). Energy weighted-averages for F_{phi} and F_{hour} over all reference cases are required for use in MELISA. For this purpose LENI or AECI energy density values in kWh/m^2/y will be derived for the optimisation options of the reference cases in Task 4. These values can be multiplied by the total EU-28 areas (m^2) per reference case to obtain the total EU-28 energy consumption per reference case. The subdivision of the total EU-28 non-residential building area over the reference cases and the subdivision of the total EU-28 lit road length over the road types are estimated in this chapter.

The building area subdivision indicates that in addition to office spaces the lighting energy consumption in circulation and sanitary areas, manufacturing areas, storeroom/warehouses and shops is also significant. This will be taken into account when selecting the reference cases in Task 4.

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)[81]. This study was performed in parallel to the Lot 37 Lighting Systems study and was concluded in October 2015.

MELISA has been developed on request of the European Commission with the aim to harmonise 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 scenario analyses in Task 7 of the Lighting Systems study.

A description of the October 2015 version of MELISA can be found in the Task 7 report of the Light Sources study[82]. During the 2016 Impact Assessment for light sources MELISA has been updated, incorporating new input supplied by industry association LightingEurope [83]. In the Lighting Systems study the last available version of MELISA of July 2016 will be used.

MELISA reasons in terms of light sources or lamps, not in terms of luminaires. Sales (replacement and new), average lifetime, installed stock, average luminous flux, average power, etc. all refer to light sources or lamps. Although MELISA distinguishes integrated LED luminaires, the associated data actually refer to the light sources contained in those luminaires. E.g. if a classical office luminaire with two LFL T8 is replaced by a single integrated LED luminaire, this still counts as two LED light sources in MELISA (light sources are replaced 1 on 1). These LED light sources inherit the luminous flux and the annual operating hours of the light sources they replace.

[81] http://ecodesign-lightsources.eu/documents

[82] http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task7%20Final%2020151031.pdf, Annexes D, E and F.

[83] These changes mainly regard the lifetime (longer), average luminous flux, power and efficacy of LFL and HID-lamps. The lifetime for LEDs substituting LFL and HID was also increased. To enable lifetime to be variable with the years, a lifetime distribution was introduced for LFL T8t, LFL T5, HPS, MH and LEDs substituting these lamps. The main effect of these changes, with respect to results reported in Task 7 of the Light Sources study, was that energy savings in 2020 and 2025 slightly decreased while savings in 2030 increased.

For application of MELISA in the Lighting Systems study, which mainly reasons in terms of luminaires or spaces to be illuminated, this means that sales and stock data should not be used or be used with care, because they do not refer to quantities of luminaires. Rather, the luminous flux sold in a given year or the total installed luminous flux should be used as a point of departure for the systems analysis.

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 (light source) 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 [84].

Although not shown in Table 2-1, 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 (residential lighting systems are not in the scope). Consequently the Lighting Systems study will use only the non-residential data from MELISA.

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.
The electricity consumption is multiplied by the electricity rates (euros/kWh)[85] 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.

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[86], in particular 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.

The input and output data of MELISA were extensively checked against other sources and also discussed with stakeholders in the course of the Light Sources study[87]. In

[84] For details see the Task 7 report of the Light Sources study.
[85] Separate rates are used for residential and non-residential applications. Until 2013 the rates are based on Eurostat. For following years an escalation rate of 4% per year is applied. Rates are in fixed euros 2010, inflation corrected. For the scenario analyses in Task 7, no discount factor is applied.
[86] http://ecodesign-lightsources.eu/
[87] See the Task 2, 3 and 4 reports of the Light Sources study.

particular, the sales data are based on a mix of data from 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 the average annual operating hours for LFL and the sales volumes of HID-lamps.

The MELISA data are therefore considered to be the best available basis for the analyses to be conducted in the Lighting Systems study.

Table 2-1 Light source base cases distinguished in the MELISA model. The shift in sales from classical technology base cases (on the left) to LED base cases (on the right) is one of the main mechanisms in the MELISA scenarios.

LFL T12 **LFL T8 halo-phosphor (T8h)** **LFL T8 tri-phosphor (T8t)** **LFL T5 (new 14-80 W) incl. circular** **LFL other (old T5 ≤ 13 W, special FL) (LFL X)**	→	**LED Retrofit lamps for LFL replacement** **Integrated LED luminaires for LFL applications**
High-Pressure Mercury (HPM) **High-Pressure Sodium (HPS)** **Metal Halide lamps (CMH, QMH)**	→	**LED Retrofit lamps for HID replacement** **Integrated LED luminaires for HID applications**
Compact Fluorescent Lamps without integrated ballast (CFLni)	→	**LED Retrofit lamps for CFLni replacement** **Integrated LED luminaires for CFLni applications**
Halogen Low-Voltage mirrored (HL LV R) **(MR11, MR16, etc. GU4, GU5.3 caps)** **Halogen Mains-Voltage reflector (HL MV X)** **(R-lamps, PAR-lamps, etc., GU10 or E-cap)** **Incandescent reflector lamps (GLS R)**	→	**LED Retrofit lamps for DLS replacement** **Integrated LED luminaires for DLS applications**
Halogen LV capsules (HL LV C) G4, GY6.35 cap **Halogen MV capsules (HL MV C)** G9 cap **Halogen MV, GLS substitute (HL MV E)** E-cap **Incandescent non-reflector (GLS X)** **Compact Fluorescent Lamps with integrated ballast (CFLi)** **Halogen MV linear (HL MV L)** R7s-cap	→	**LED Retrofit lamps for NDLS replacement** **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 extension for the Lighting Systems study

For the scenario analysis of lighting system improvements, to be performed in Task 7, an extension to MELISA has been implemented. Although details will be discussed in Task 7, the main methodology is explained here, with the aim to clarify which data have to be generated during the study to enable the scenario analysis.

In subsequent tasks of the study, various lighting system designs will be developed for each of a series of reference cases, i.e. indoor areas of a specific type (e.g. office, corridor, shop, manufacturing area) or outdoor lengths of roads of a specific type (e.g. motorway, secondary road, road in residential quarters). Typically, four designs are made for each indoor reference case:

- Base Case design: intends to represent the average current practice,
- Optimised design: improved layout of the luminaires in the space and application of luminaires with higher light output efficacy, while maintaining the lighting requirements in the task areas. With respect to the base case, the optimised design leads to a lower total luminous flux installed in the space. The ratio of the installed flux of the optimised design and the installed flux of the base case design is defined as the **Flux Factor (F_{phi})**[88].
- Optimised design + Controls: in addition to the optimised design, sensors and controls are added to the system so that lights can be dimmed or switched off in function of daylight availability and/or room occupancy. With respect to the base case, the 'optimised design + controls' leads to lower annual full-power equivalent (fpe) operating hours. The ratio of the hours of the controlled design and the hours of the base case design is defined as the **Hour Factor (Fhour)**.

[88] The reduction of the luminous flux can occur due to a reduction of the number of luminaires in the room, due to a reduction of the luminous flux per luminaire, or a combination of both. In all cases this is handled only by the Flux Factor, i.e. a Sales Factor to reflect the decrease of the installed number of light sources is not used.

- Optimised design + Controls + Surfaces: the difference with the preceding design is that room surface reflectance is also improved. This enables a better use of available daylight and a further reduction in fpe operating hours, i.e. a lower Hour Factor.

For outdoor road lighting cases, the first three designs listed above are similarly used.

Consequently, at least as regards energy aspects, the influence of lighting system improvements can be expressed in MELISA by two model factors: F_{phi} for the reduction in installed luminous flux (at light source level) and F_{hour} for the reduction of the full-power equivalent annual operating hours.

For a given light source efficacy, the electricity consumption is directly proportional to the installed luminous flux (of light sources) and to the annual fpe operating hours. Consequently, the electricity consumption after implementation of lighting system improvements (E_{after}) can be derived from the one before lighting system improvements (E_{before}) using:

$$\mathbf{E_{after} = E_{before} * F_{phi}(stock\ average) * F_{hour}(stock\ average)}$$

E_{before} is taken from an existing MELISA reference scenario (BAU- or ECO-scenario for light sources[89]). These scenarios already include a shift from classical lighting technologies to LED lighting products and consequently already take into account the energy savings due to improvements in light source efficacy. Taking a MELISA scenario as reference, and applying the factors F_{phi} and F_{hour} to include effects of lighting system improvements, ensures compatibility between the Light Sources study and the Lighting Systems study and also avoids that savings due to light source efficacy improvements are counted double.

Note that the above formula uses a stock average for F_{phi} and F_{hour}: the applied factors should be representative averages for the stock for which E_{before} has been derived. Calculation of these averages has three aspects:

1) In general, the factors F_{phi} and F_{hour} will be different for each reference case (e.g. offices, corridors, shops, manufacturing halls, various road types). Considering that the reference cases do not have equal importance in terms of energy impact, an energy-weighted average for both factors has to be determined.
2) The reference cases for which lighting designs will be developed will inevitably not cover all non-residential lighting applications. It will have to be determined which part of E_{before} is covered by the reference cases, and which part is not. For the non-covered part it has to be decided which F_{phi} and F_{hour} apply. The most logical choices are F_{phi}=F_{hour}=1 (no system improvements for cases that have not been studied), or F_{phi} and F_{hour} identical to the average of the studied cases. The energy for non-covered cases is included in E_{before}, so the energy-

[89] This intends to represent the current practice as regards the use and installation of (optimised) lighting systems. The BAU scenario for light sources includes a shift towards LED lighting products that is assumed to take place in absence of additional ecodesign regulations on light sources. The ECO-scenario for light sources accelerates this shift by phasing out some conventional lamp technologies by means of new ecodesign measures for light sources. The process of defining such new measures is still ongoing (August 2016).

weighted averages for F_{phi} and F_{hour} should also take into account this non-covered part.

3) In the reference scenarios of MELISA, F_{phi}=F_{hour}=1 will be assumed for all years (no system savings). In the system scenarios, F_{phi} and F_{hour} smaller than 1 will be introduced starting from a given year in which a measure on lighting systems comes into force. However, the energy-weighted values described at the previous points apply to the 'sales' (new installed or renovated systems) in a given year, and not directly to the entire stock for which E_{before} has been derived. Consequently 'stock-averages' have to be determined from the 'sales-averages'. This stock-averaging is already done in MELISA for other parameters and does not present particular problems.

Regarding the above point 1), the electricity consumption density in kWh/m^2/y will anyway be derived for each reference case design, as it has been chosen as the main parameter on which to evaluate lighting system designs (LENI for indoor, AECI for road lighting). Consequently, if total EU-28 areas per reference case would be available, the total EU-28 electricity consumption for each reference case could be calculated (kWh/m^2/y * m^2), thus clarifying the share of each reference case in the total electricity of all reference cases. This share can then be used as weighting factor to determine the average of F_{phi} and F_{hour} over all reference cases.

Regarding the above point 2), comparing the electricity of the reference cases with the total non-residential energy in MELISA, the share of total energy covered by the reference cases can be determined and thus also the non-covered share.

Consequently, the study has to estimate the total EU-28 areas per reference case, i.e. the subdivision of the total EU-28 building area in room/space types, and the subdivision of the total EU-28 lit road length in road types.

Regarding cost aspects, the energy costs can be calculated multiplying the electricity consumption (E_{after} or E_{before}) by the electricity rates already defined in MELISA for the non-residential sector.

MELISA does not provide data on the acquisition costs of luminaires (purchase and installation), so these data would have to be generated during the lighting systems study. At least the difference in luminaire costs between the system design options should be estimated for each reference case, including also additional design costs and/or additional costs for lighting controls.

As MELISA does not provide sales quantities for luminaires (only for light sources), the luminaire acquisition costs should preferably be provided in terms of costs per unit of installed light source flux (euros/klm). The weighted-average costs/klm over all reference cases can then be multiplied by the total EU-28 sold flux in a given year (with or without multiplication by the Flux Factor) to obtain the total EU-28 acquisition costs for each lighting design option.

Consequently, the study would have to estimate the difference in luminaire acquisition costs (purchase and installation), in terms of euros/klm, between the base case design and the improved designs, including additional design costs and/or lighting control costs where appropriate.

As the study does not include MEErP Tasks 5 and 6, the generation of these acquisition cost data will be limited and preliminary.

For further details on the scenario analysis and on the implementation of lighting system improvements in MELISA, see Task 7.

2.2 Generic economic data

2.2.1 Introduction

The aim of 'Generic economic data' according to the MEErP is to give an overview, for the product group that is 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 [90], shipped, imported or exported as a whole. Consequently they are not distinguished as a product in the Eurostat production and trade statistics (Europroms-PRODCOM) [91].

Trade data and apparent sales can be derived from Eurostat data for some of the components of Lighting Systems, in particular for light sources, ballasts/control gears and some types of luminaires. For other components such as sensors, controls, dimmers, communication electronics (WiFi, Zigbee, DALI, etc.), and wiring this is more difficult. However, relating these component sales to system sales is not feasible.

As explained in the previous paragraph (and to be further detailed in Task 7), the analysis of the impacts of lighting system improvements can also be performed in the absence of sales data on lighting systems, by relating these improvements (by means of Flux Factor and Hour Factor) to the total EU-28 installed luminous flux (at light source level) and the total EU-28 full-power equivalent annual operating hours in the non-residential sector, as already defined in the MELISA model.
Essentially, the only 'market' data required are the total EU-28 building or room areas per lighting system reference case (e.g. offices, corridors, shops, manufacturing halls) and the total EU-28 size/length per road type (e.g. motorways, secondary roads, residential roads)[92].

Consequently, market data on lighting systems are not available, and market data on lighting system components will be used in the study in an indirect way (through the MELISA data). For completeness sake some market data on lighting system components are reported below, but the focus is on the subdivision of the non-residential building area and on the total EU-28 road size/length per type.

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, and, as will be shown in Task 7, potential energy savings are certainly significant.

[90] It could be stated that they are assembled 'on-site'
[91] 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.
[92] As the scope of this study has been limited in Task 1 to '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', areas in residential buildings need not be considered.

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[93]. Updated sales and stock previsions (MELISA version July 2016) that are useful as background information for the Lighting System study are included in Annex C. This annex provides sales and stock for the period 1990-2030, for the non-residential parts of the LFL-, HID- and CFLni-application groups. These data are for the light source BAU-scenario as defined in Task 7 of the Light Sources study [94].

It can be concluded from these data that LFL T12, LFL T8 halo-phosphor and HPM-lamps 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.

- 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 remain unreliable [95]:

- 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

[93] http://ecodesign-lightsources.eu/
[94] 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.
[95] 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

(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 [96], 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 in 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.

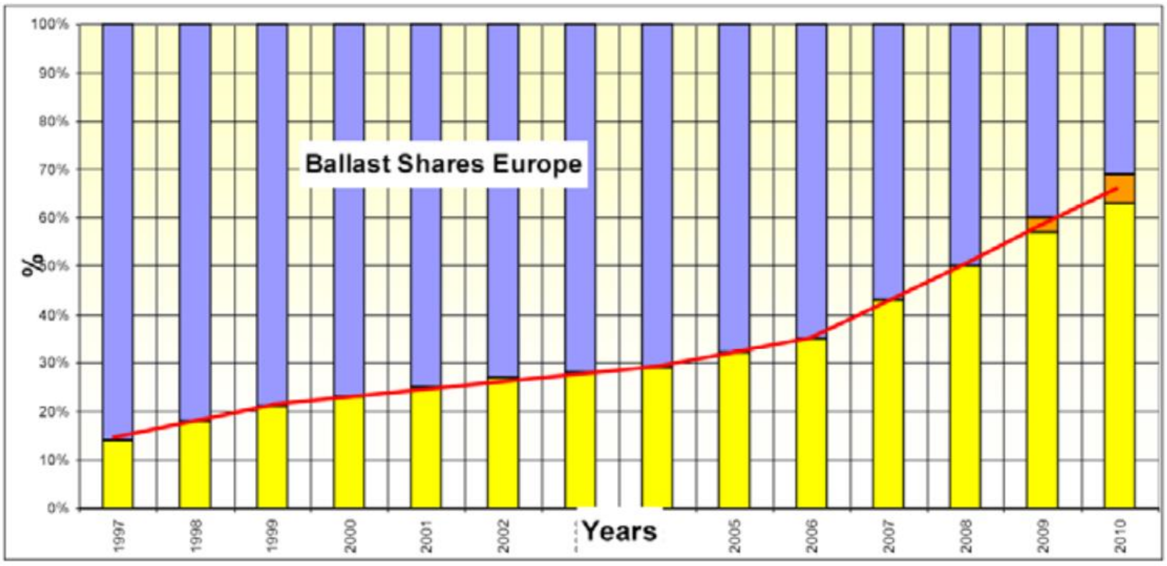

Figure 2-1 Market share (1997-2008) and expected market share (2009-2010) of European ballast sales by type for use with linear fluorescent lamps (blue=magnetic ballast; yellow=electronic ballast; orange=tolerance band) (Source: [96])

[96] 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

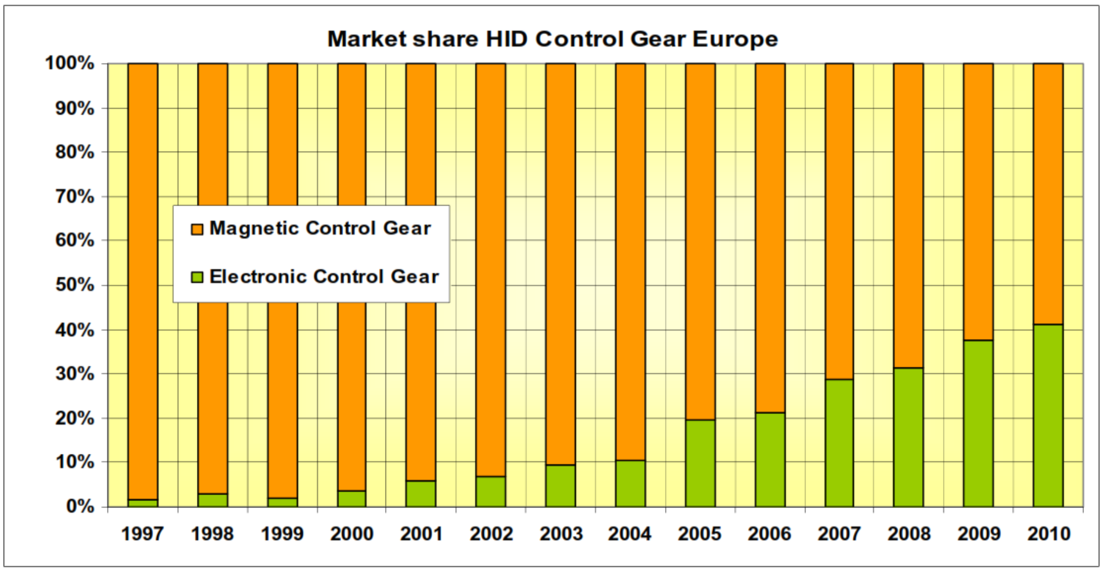

Figure 2-2 Market share (1997-2010) of the European ballast sales by type for use with high-intensity discharge lamps (orange=magnetic ballast; green=electronic ballast) (Source: [96])

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 E. 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 (HID-)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 per luminaire[97].

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 [98], with an average value of around 9 euros / light source (incl. VAT for residential, fixed 2010 euros).

[97] This price is not representative for the professional luminaires taken into account in this study.
[98] Data taken from the MELISA model.

Consequently the number of luminaires sold was roughly one fifth of the number of light sources.

These luminaires sales figures include for example residential luminaires while HID-road lighting luminaires seem to be excluded. Therefore these data are not directly applicable for the scope as defined in Task 1.

2.2.5 Sales of sensors

The sensors of main interest for lighting systems are daylight sensors and occupancy sensors (occupancy-, 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 than lighting systems.

Consequently: no useful trade and sales data on sensors for lighting systems is available from PRODCOM statistics.

2.2.6 Sales and stock of dimmers and other control devices

According to CECAPI [99], 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 100, 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.

[99] 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.
[100] Actually the countries covered by the study are France, Germany, Italy, UK, Denmark, Finland, Norway, Sweden, both residential and non-residential sectors.

- 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 25% are installed in the non-residential sector (75% residential).

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 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.

According to the lighting industry[101], 5 to 10% of the non-residential buildings has a controlled lighting system and 5 to 7% of street lighting is controlled.

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.

[101] Lighting Europe comments in draft Task 2 report.

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'[102], 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 Non-residential building areas per type of space

Aim

As explained in section2.1.2, this study will estimate the potential savings due to indoor lighting system improvements for individual reference cases (e.g. cellular offices, open-plan offices, shops, manufacturing areas, circulation areas, etc.). Amongst others, a LENI in kWh/m^2/y will be derived for each system optimisation option (e.g. base case, optimised design with or without controls) of each reference case.
To enable the determination of an energy-weighted average of the improvements over all reference cases, and to enable an estimate of the part of the total non-residential energy that is covered by the studied reference cases, the annual energy consumption for each reference case has to be estimated. This can be done by multiplying the LENI values by the corresponding total EU-28 building area (m^2). The aim of this paragraph is to define these areas.

Source

The reference areas for lighting in non-residential buildings have been derived starting from the report on EU-28 Building Heat Demand [103]. This report was prepared on request of the European Commission, with the aim to harmonise 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[103] 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, architectural 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.

[102] http://erp4cables.net/
[103] "Average EU building heat load for HVAC equipment", final report, René Kemna (VHK) for the European Commission, August 2014 (chapter 4, volumes and surfaces)

Considering that the data sources for the report are considerably wider than just Eurostat statistics, that the area survey was developed specifically to harmonise 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[103] 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[104]. In addition, data from the European Parking Association regarding areas for parking in structures have been used [105].

As far as possible considering information availability, the same building and room types were distinguished as used in EN-15193 for the definition of annual operating hours and absence factors. See additional information in Annex F.

Non-residential building area per type of building

The result of the area-analysis per type of non-residential building is shown in Table 2-3. 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%) [106].

The table also compares the new estimate with data previously used in Task 0 based on a 2013 study by Waide[107] and on data reported by BPIE[108]. The new total area (11773 Mm^2) is almost twice as large as the previous value (5888 Mm^2).
In the opinion of the lighting industry[109] the new estimated area data are to be preferred for the purposes of the Lighting Systems study. They consider the previous total of 5888 Mm^2 too low. In addition, comparing with their own market analyses, they recognize the approximate equality of total EU-28 areas for industry, retail and offices.

Table 2-3 Summary per building type of total EU-28 non-residential lit building areas (in million square meters, M m^2) and comparison with data used previously in Task 0 based on BPIE[108].

	EU-27 area M m^2		Share % of total	
sector	Task 0 BPIE	Current analysis	Task 0	Current analysis
Education	1001	1302	17%	11%
Hotels & Restaurants	648	754	11%	6%
Hospitals (&HealthCare)	412	907	7%	8%

[104] See in particular table 13 of the Building Heat Demand report, taken from 'Réglémentation Thermique 2012 (France)'.
[105] '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
[106] 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. It also implies approximately 23 m^2 of illuminated non-residential building area per EU-28 inhabitant (2015).
[107] Waide (2013): 'The scope for energy and CO2 savings in the EU through the use of building automation technology', http://www.leonardo-energy.org/
[108] http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf
[109] Lighting Europe comments on draft Task 2.

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%**

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 2-4; see Annex F for further details.

The largest area shares have been found for circulation areas and toilets (including e.g. corridors, staircases, entrance halls, reception areas, toilets, showers, wardrobes, 20.8%), offices (10.1% cellular/small and 5.2% open/landscape, total 15.3%), manufacturing areas (12.5%), and storerooms and warehouses (6.6%). This indicates on which type of spaces the Lighting Systems study should focus.

The table also indicates a subtotal of 6896 Mm^2 (58.6%) which is approximately the area covered by the reference cases for which optimised lighting system designs are developed in later tasks.

Table 2-4 Summary per room type of EU-28 total non-residential lit 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 (including e.g. corridors, staircases, entrance halls, reception areas, toilets, showers, wardrobes)	2449	20.8%
Offices (cellular in office buildings and general small offices in non-office buildings)	1185	10.1%
Offices (open space, landscape type)	609	5.2%
Manufacturing area	1476	12.5%
Storerooms / Warehouses	774	6.6%
Shops > 30 m2	402	3.4%
Subtotal (considered in reference cases)	**6896**	**58.6%**
Shops < 30 m2	643	5.5%
Class rooms and similar	573	4.9%
Technical and service areas	502	4.3%
Eating and drinking areas	496	4.2%
Hospital and healthcare wards/ bedrooms/ examination/ treatment rooms	371	3.1%
Meeting rooms	362	3.1%
Theatres, Dancings, Amusement parks	358	3.0%
Parking in structures	290	2.5%
Sports Halls	242	2.1%
Other areas	1041	8.8%
Total non-residential building area	**11773**	**100.0%**

At an early stage of the study, it has been verified if the estimated building area subdivision, combined with minimum lighting requirements from EN 12464-1:2011 (lux = lm/m^2) and power density values Pjlx (W/m^2/lux = W/lm) suggested in prEN15193-1:2014 table C.1, leads to total EU-28 installed lighting capacity and power that are similar to those in MELISA. Details of these crosschecks are explained in Annex F.

Although these crosschecks are preliminary and approximate, involving many assumptions, the results were encouraging (good match with MELISA), thus increasing the confidence in the building area data. Additional information showing that the building area data are reasonable for use in this study will be presented in the scenario analysis of Task 7.

2.2.10 Quantity, length and types of roads

Eurostat provides road transport infrastructure statistics[110] . Even though the Eurostat data is not used further in the report, it is shown for completeness. The Eurostat data is incomplete as data for certain countries is missing in certain years. Therefore other sources and data will be used for further estimations.
The Eurostat data contain the following road categories:

- Motorways: total length reported is 63 660 km in EU28 (2010), with large networks in Spain, France and Germany.
- E-roads: which belong typically to EN 13201-2 or 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: total length reported is 3 616 472 km in the EU28 (2010).
- Other roads inside or outside built up areas: total length reported is identical to -state, province and communal roads.

Another source of information for the lengths of different road types in the different EU28 Member States are the "European Road Statistics" of the European Road Federation for 2011[111] , see Table 2-5. This data is more reliable and can be further used to develop a road lighting market model. It should be noted that this data does not include statistics on lit roads and therefore further processing is necessary.

Table 2-5 Length of total road network by category in km in 2011 (ERF (2014))

Road length statistics	Motorways	Main or national roads	Secondary or regional roads	Other roads	Total	Population
Member State	**length (km)**	**length (km)**	**length (km)**	**length (km)**	**length (km)**	**capita**
Belgium	1 763	13 229	1 349	138 869	155 210	8 551 081
Bulgaria	458	2 970	4 030	12 054	19 512	11 336 943
Czech Republic	745	6 254	48 743	74 919	130 661	7 199 931
Denmark	1 143	2 697	35 045	35 045	73 930	4 244 995
Germany	12 845	39 673	178 184	413 000	643 517	873 003
Estonia	115	3 896	12 458	42 299	58 768	10 536 043
Ireland	900	4 780	11 631	78 958	96 269	5 649 584
Greece	1 197	9 299	30 864	75 600	116 960	1 311 505

[110] http://ec.europa.eu/eurostat/web/transport/data/database
[111] ERF, European Road Statistics 2011, http://www.irfnet.eu/index.php/publications/publications/european-road-statistics-handbook

Spain	14 554	15 056	136 298	501 053	666 961	5 478 486
France	11 412	9 745	377 857	654 201	1 053 215	66 175 754
Croatia	1 254	6 843	10 967	10 346	29 410	80 709 056
Italy	6 668	20 773	151 583	312 100	491 124	10 977 945
Cyprus	257	2 197	2 779	4 732	9 965	9 863 193
Latvia	N.A.	1 651	5 317	61 549	68 517	4 602 854
Lithuania	309	6 367	14 589	51 064	72 329	60 944 960
Luxembourg	152	837	946	946	2 880	1 985 887
Hungary	1 516	6 824	23 358	169 263	200 961	2 901 039
Malta	N.A.	184	665	1 379	2 228	562 848
The Netherlands	2 658	2 462	7 802	126 373	139 295	426 144
Austria	1 719	10 013	23 639	88 753	124 124	16 876 904
Poland	1 070	17 731	156 219	237 244	412 264	38 499 953
Portugal	2 737	6 284	4 420	63 900	77 341	10 367 550
Romania	350	16 690	35 374	31 639	84 053	19 909 323
Slovenia	768	817	5 144	32 248	38 976	5 416 851
Slovakia	419	3 507	14 050	25 351	43 328	2 066 511
Finland	790	12 539	13 573	51 236	78 138	46 390 269
Sweden	1 920	13 465	83 079	116 832	215 296	9 721 642
United Kingdom	3 686	49 067	122 665	244 334	419 752	64 643 370
EU28	**71 405**	**285 849**	**1 512 628**	**3 655 287**	**5 524 984**	**508 223 624**

Notes: the definition of road types varies from country to country, the data are therefore not comparable.
«other roads» sometimes includes roads without a hard surface.
Denmark and Luxemburg do not give a distribution between secondary or regional roads but is assumed 50/50

The lot 9 preparatory study[112] on street lighting sent out a questionnaire in 2006 to estimate the share of lit roads in 1990. The following answers were received: 10% of so-called category fast traffic roads or typically motorways, 15% of so-called mixed traffic roads or typically intercommunal roads and 30% of so-called slow traffic roads or typically roads in residential areas are lit.
However in a later section (2.2.12.1) a new stock estimate is made on the installed stock in 2015 and a new cross-check can be done with typical information on average pole distances. It was judged that the expert estimation for 1990 for the distribution between these categories is correct but that the amount of roads with lighting is higher in 2015. The new results are shown in Table 2-6.

Table 2-6 Estimated share of lit roads in 2015

	Motorways	Main or national roads	Secondary or regional roads	Other roads
EU28 road lenght[km]	71 405	285 849	1 512 628	3 655 287
2015 share lit (%) corrected	12%	12%	18%	37%

The lighting industry[113] provided an estimate for 2016 on which most typical road classes according to EN 13201-2 correspond to these road statistics, it can be used for selecting reference designs in Task 3. The result of this estimate can be found in Table 2-7.

[112] www.eup4light.net
[113] http://www.lightingeurope.org/

Table 2-7 Typical lighting class installed according to EN 13201-2 on European roads and their estimated share(source: Lighting Europe)

ERF category	**Motorway**	**Main or national roads**	**Secondary or regional roads**		**Other roads**		
Subcategory	**Motorways**	**Main or national roads**	**Rural roads or mixed with residential**	**Mixed conflict**	**Mixed traffic**	**Residential streets P4**	**Residential streets M5**
share(%) in ERF road category	100%	100%	92%	8%	40%	30%	30%
Typical EN 13201-2 class	M2	M3	M4	C3	P2	P4	M5

2.2.11 Additional market and stock data for indoor lighting

2.2.11.1 2007 installed base lighting control (lot 8)

The following data can be reused from the preparatory study on office lighting lot 8[112]: 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.

Type of control system used	Data	Ref year	Source	Region
Manual control	97%	2000	DEFU, 2001 in IEA, 2006	Europe-6[114]
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[115]	12%	2002	SenterNovem[116]	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[117]	Netherlands
	22%	2003		
Switching on/off by presence detection	8%		Kantoor 2000	Belgium
Occupancy detection	10%	2002	SenterNovem	Netherlands
	12%	2003		

Table 2-8 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 2-9 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, which at least partly offsets the energy savings achieved during office hours.
At maximum stand by power is 8760 h/y but in many indoor applications the power is switched off during the night and weekend, so energy saving will be higher. For many outdoor applications the lighting is often switched centrally, so these installations are not powered during the day and as a consequencedo not have standby losses.

[114] Results from a survey in six EU countries; No full survey exists for Europe as a whole
[115] (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.
[116] SenterNovem (2003) Monitor Energiebesparende maatregelen. Rapportage EBM
[117] SenterNovem (2003) Monitor Energiebesparende maatregelen. Rapportage EBM

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[116] that this technique is already much more applied.

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.
According to the lighting industry[118] the stock (= today's park) of 5 to 10% of non-residential buildings is controlled and 5-7% of street lighting is controlled.
Also, typical standby power data for indoor controls is:
- Controls embedded in luminaire typically have 1W standby losses.
- Standalone controls controlling multiple luminaire are in the order of 2-4W. For 4 luminaires controlled by one controller this would mean 1W standby per luminaire.
Outdoor lighting is often switched centrally, so these installations are not powered during the day and as a consequence do not have standby losses.

2.2.11.2 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.

2.2.11.3 Direct lighting versus indirect lighting luminaires in offices

Source lot 8 (2007):
In this section we focus on the shares of A1[119] versus A2[120] 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

[118] Lighting Europe comments in draft Task 2 report.
[119] Only direct light, often ceiling mounted
[120] Direct/indirect light, often suspended

luminaires), in new installations 20% (Belgium), 30% (Spain) to 50% (Germany) are suspended luminaries with direct/indirect light.

%		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 2-10 Use of lighting technology in percentage for the public and private office buildings (Source: DEFU, 2001)

2.2.12 Additional market and stock data for road lighting

2.2.12.1 Road lighting luminaires per capita and stock growth

In the ecodesign street lighting study (Lot 9 (2007)), scattered data on the number of luminaires per capita were retrieved from various sources for modelling the stock in 2005.

This 2005 data is reviewed with the following sources to estimate the stock in 2015:

- Accurate data were supplied from Belgium and Sweden a recent questionnaire complementary to the GPP street lighting study[121] for 2005 versus 2015. It showed that in Belgium the stock increased from 2 005 000 (2005) to 2 154 280 (2015) or 0.48 % per year and in the Stockholm area from 144 122 (2005) to 147 626 (2015) or 0.18 % per year. The Swedish stock data from 2005 has been updated proportional to the Stockholm growth rate data. This stock increase is a relative low figure and is supported by the fact that the EU has a mature road infrastructure which requires relatively low levels of new road construction each year;
- New literature data from the ESOLI FP 7 project[122] on road lighting stock in the Czech Republic, Finland, Germany, the Netherlands and the UK. Also for France there is updated data available from literature[123];

[121] http://susproc.jrc.ec.europa.eu/Street_lighting_and_Traffic_signs/index.html
[122] ESOLI (2012): ESOLI project work Package 2, 'Assessment of framework conditions' report on market and framework conditions_131005, available on http://www.esoli.org/index.php?option=com_content&view=article&id=82&Itemid=93&lang=en
[123] AFE (2015): 'Eclairage public : toutes les réponses à vos questions - Cahier de fiches AFE', http://www.afe-eclairage.fr/ressources-documentaires.html?p=0&g=2

- For other countries the average growth rate of 0.33 % (the average for Belgium and Stockholm) was used to estimate the 2015 stock versus 2005.
- Bulgaria, Croatia and Romania were not part of the EU in 2005. No accurate data was supplied in the enquiry and therefore 2015 data was extrapolated from the European average.

An overview of the estimated stock of installed road lighting luminaires in the EU28 in 2005 and 2015 is in Table 2-11 based on the previous data and assumptions. It shows also that there are strong differences between countries. In general, countries with a relative high share of habitants living in apartments will have a relative low amount of luminaires per capita. For example in Belgium (0.19) a large share of the population lives in single family houses resulting in a relative high amount of luminaires compared to EU28 the average (0.13). Another potential explanation is the use of low wattage lamps with short distance between the poles, this will result in a relative high amount of luminaires per capita. There is in the EU28 on average 0.13 luminaire installed per capita.

Table 2-11 Estimated stock of road lighting luminaires in EU-28 in 2005 and 2015

Country	Habitants 2015	Total stock luminaires 2005	Total stock luminaires 2015	Luminaires per capita 2015
Austria	8 551 081	1 000 000	1 033 494	0.12
Belgium	11 336 943	2 005 000	2 154 280	0.19
Bulgaria	7 199 931		910 708	0.13
Croatia	4 244 995		536 943	0.13
Cyprus	873 003	88 000	90 948	0.10
Czech republic	10 536 043	300 000	1 300 000	0.12
Denmark	5 649 584	780 000	806 126	0.14
Estonia	1 311 505	50 000	51 675	0.04
Finland	5 478 486	400 000	1 100 000	0.20
France	66 175 754	9 000 000	9 000 000	0.14
Germany	80 709 056	9 250 000	9 250 000	0.11
Greece	10 977 945	900 000	930 145	0.08
Hungary	9 863 193	600 000	620 097	0.06
Ireland	4 602 854	401 000	414 431	0.09
Italy	60 944 960	9 000 000	9 301 449	0.15
Latvia	1 985 887	85 000	87 847	0.04
Lithuania	2 901 039	125 000	129 187	0.04
Luxembourg	562 848	61 000	63 043	0.11
Malta	426 144	45 000	46 507	0.11
Netherlands	16 876 904	2 500 000	3 652 286	0.22
Poland	38 499 953	4 200 000	4 340 676	0.11
Portugal	10 367 550	1 100 000	1 136 844	0.11
Romania	19 909 323		2 518 300	0.13
Slovakia	5 416 851	200 000	206 699	0.04
Slovenia	2 066 511	74 000	76 479	0.04
Spain	46 390 269	4 200 000	4 340 676	0.09
Sweden	9 721 642	2 500 000	2 545 366	0.26
UK	64 643 370	7 851 000	7 640 227	0.12
EU28	**508 223 624**		**64 284 433**	**0.13**

As a consequence the total EU28 luminaire stock data and stock growth can be combined with the relative data of road categories (section 2.2.10) luminaire life time (section 3.4.1.2) to estimate detailed stock and sales, see Table 2-12.

Table 2-12 Road luminaire stock and sales model

			Secondary or regional roads		Other roads			
Subcategory	Motorways	Main or national roads	rural roads or mixed with residential	mixed conflict	mixed traffic	Residential streets P4	Residential streets M5	Total
share(%) in ERF road category (source Lighting Europe)	100%	100%	92%	8%	40%	30%	30%	
EU 28 road length [km]	71 405	285 849	1 391 617	121 010	1 462 115	1 096 586	1 096 586	
Typical EN 13201-2 class	M2	M3	M4(&P4)	C3	P2	P4	M5(&P5)	
Stock estimate 2015	175 855	782 207	8 568 145	745 056	21 605 268	16 203 951	16 203 951	64 284 433
Average economic life time(years)	30	30	30	30	30	30	30	
Annual luminaire sales stock growth	0,33%	0,33%	0,33%	0,33%	0,33%	0,33%	0,33%	
Annual luminaire sales for replacement 2015	5 862	26 074	285 605	24 835	720 176	540 132	540 132	2 142 814
Annual luminaires sales for new road 2015	580	2 581	28 275	2 459	71 297	53 473	53 473	212 139
Stock forecast 2020	178 776	795 199	8 710 455	757 431	21 964 116	16 473 087	16 473 087	65 352 150
Annual luminaire sales for replacement 2020	5 959	26 507	290 349	25 248	732 137	549 103	549 103	2 178 405
Annual luminaire sales for new road 2020	590	2 624	28 745	2 500	72 482	54 361	54 361	215 662
Stock forecast 2030	184 764	821 833	9 002 207	782 801	22 699 790	17 024 843	17 024 843	67 541 080
Annual luminaire sales for replacement 2030	6 159	27 394	300 074	26 093	756 660	567 495	567 495	2 251 369
Annual luminaire sales for new road 2030	610	2 712	29 707	2 583	74 909	56 182	56 182	222 886

2.2.12.2 Lamp technologies used in road lighting

The ecodesign street lighting study (Lot 9 (2007)) also contained an estimate on how lamp technologies are used in countries in the EU in 2005, see Table 2-13. Strong differences between countries in lamp distribution can be observed. Some countries had already relative low share of inefficient HPM lamps, e.g. Belgium, Ireland, Netherlands, Sweden and the UK, independent from the fact that they will be banned from the market.

For 2015 no new data is available. However a new average for the total EU28 is made based on the following assumptions:

- EC Regulation 245/2009 phases out inefficient HPM and FL lamp types, see section 1.5.1.3. It can therefore be assumed that HPM and FL were substituted by HPS and MH lamps between 2010 and 2014 with a replacement rate equivalent to the average life time of 30 years;
- Precise data on the uptake of LED luminaires in road lighting is missing and therefore assumptions were made. Before 2014 it can be assumed that the market uptake for LED luminaires remained relative low and therefore for simplicity they are neglected. In 2015 however it is assumed that LED luminaires became the mainstream luminaire for replacement and new sales. Therefore the assumption of 90 % LED and 10 % HID sales in 2015 was made. A recent visit (April 2016) to the light and building trade fair[124] learned that nearly only LED luminaires were on display and the manufacturers indicated that new projects are mainly based on LED luminaires. This resulted in the

[124] http://light-building.messefrankfurt.com/frankfurt/en/besucher/willkommen.html

assumption that the stock change of 2015 is towards LED. Due to this transition accurate stock projections are difficult.

The estimated share of lamp technologies in the EU 28 in 2015 are presented in the last row of Table 2-13 and in Figure 2-3.

Table 2-13 Use of different lamp technologies per country in 2005 and estimated EU28 average in 2015

Country	HPM 2005 %	HPS 2005 %	LPS 2005 %	MH 2005 %	FL 2005 %	LED 2005 %
Austria	30%	67%	0%	3%	0%	0%
Belgium	5%	51%	32%	3%	7%	0%
Bulgaria	33%	48%	9%	2%	8%	0%
Croatia	33%	48%	9%	2%	8%	0%
Cyprus	48%	49%	0%	3%	0%	0%
Czech Republic	40%	56%	0%	2%	2%	0%
Denmark	40%	35%	3%	3%	20%	0%
Estonia	40%	56%	0%	2%	2%	0%
Finland	40%	54%	3%	3%	0%	0%
France	33%	62%	0%	5%	0%	0%
Germany	45%	34%	0%	3%	18%	0%
Greece	50%	42%	0%	3%	5%	0%
Hungary	33%	67%	0%	0%	0%	0%
Ireland	3%	42%	55%	0%	0%	0%
Italy	64%	28%	1%	5%	2%	0%
Latvia	40%	56%	0%	2%	2%	0%
Lithuania	40%	56%	0%	2%	2%	0%
Luxembourg	25%	71%	1%	3%	0%	0%
Malta	33%	64%	0%	3%	0%	0%
Netherlands	5%	47%	30%	3%	20%	0%
Poland	49%	50%	0%	1%	0%	0%
Portugal	30%	65%	0%	0%	5%	0%
Romania	33%	48%	9%	2%	8%	0%
Slovakia	40%	56%	0%	2%	2%	0%
Slovenia	41%	56%	0%	2%	2%	0%
Spain	20%	70%	0%	0%	10%	0%
Sweden	5%	90%	3%	3%	0%	0%
UK	0%	41%	44%	0%	15%	0%
EU28	**32.8%**	**48.5%**	**8.6%**	**2.5%**	**7.7%**	**0%**
	HPM 2015 %	**HPS 2015 %**	**LPS 2015 %**	**MH 2015 %**	**FL 2015 %**	**LED 2015 %**
EU28	**23.4%**	**53.5%**	**6.1%**	**7.7%**	**5.5%**	**3.8%**

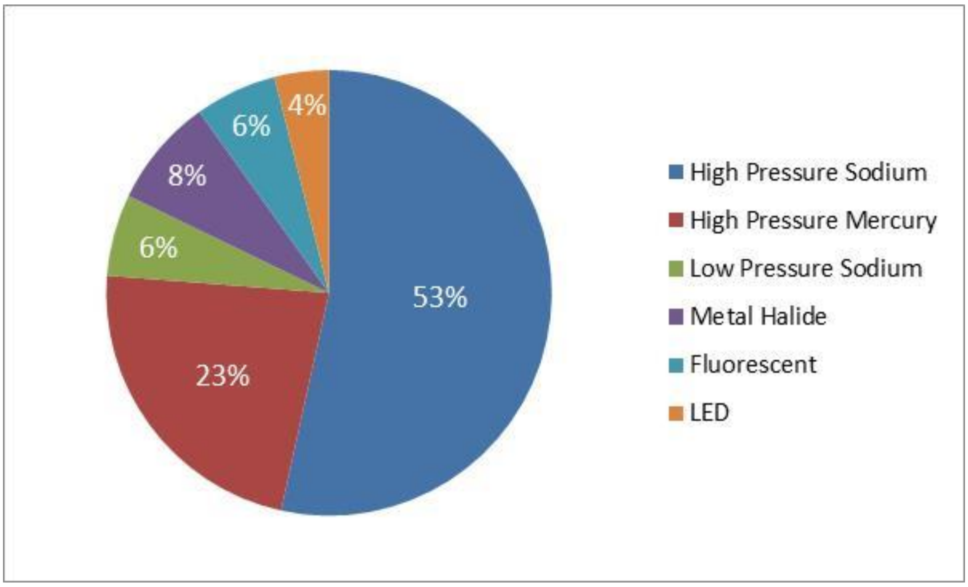

Figure 2-3 Estimate of relative share of lamp technologies used in road lighting (EU28, 2015)

2.2.12.3 Lighting point spacing and spacing to height ratio (SHR)

In order to estimate the share of lit roads and have a view on future trends, the distance between the lighting poles can be used. The distance between the lighting poles is related to their height and the type of road. The spacing between lighting poles versus the height of the luminaires, i.e. the Space to Height Ratio (SHR), can vary substantially for different types of roads and/or countries.
In the lot 9 study a questionnaire was sent out to all stakeholders. A summary of their replies in 2007 are:

- For the fast traffic road classes there was a large difference in the spacing of lighting poles in the EU, varying from 40 to 90 m. The SHR varies between 3.1 and 4.5 (e.g. 90/20, 60/15, 48/12, 40/13).
- For the mixed traffic road classes the SHR applied varies between 3.2 and 4.5 (e.g. 45/10, 50/12.5, 35/11).
- For the low traffic roads classes the SHR was between 4 and 5 (e.g. 40/8, 36/8, 25/5, 30/7, 20/4).

2.2.12.4 Estimated road lighting lamp sales and relamping

The life time of lamps used for road lighting is limited. Therefore they have to be replaced over the life time of the road lighting luminaire. Typical lamp life times are included in Table 2-14 based on a combination of lamp survival factor (LSF) and lamp luminance maintenance factor (LLMF). These data are provided in standard CIE 154:2003 and were selected according to the typical user data of the preparatory study in 2007(lot 9). Combined with the stock data from section 2.2.12.1 the total EU28 sales volumes can be estimated (see Table 2-14). HPM lamps are phased out for new sales by Regulation 245/2009 but it can be assumed that some municipalities have stocked replacement lamps to avoid new investments in more efficient lighting.
The estimates provided in Table 2-14 take into account that in road lighting it is not possible to switch lamp type in an existing luminaire because each of these lamps (HPM, FL, HPS, LPS, HM) has its own type of ballast or control gear and starter. Note

that LED is included in the luminaire sales that are previously discussed in section 2.2.12.1.

Table 2-14 Typical service life of lamps in road lighting and projected sales volumes

Lamp type	HPM	FL	HPS	LPS	MH
Years of service	3	3	4	3	2
Typical service hours	12 000	12 000	16 000	12 000	8 000
EU28 luminaire stock 2015	15 135 616	3 569 164	34 690 705	3 953 166	5 010 889
EU28 lamp sales 2015	-	1 189 721	8 672 676	1 317 722	2 505 444
Typical unit price (euro)	-	€ 4	€ 15	€ 48	€ 22
Total EU28 sales (euro)	-	€ 4 758 885	€ 130 090 145	€ 63 250 662	€ 55 119 777

2.2.12.5 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 combination of this data results in an installed stock and annual sales forecasts included inTable 2-12, the estimate for installed stock of road lighting luminaires was about 64 million light points with an annual sales of 2.3 million luminaires. Together with statistics on typical pole distances and road widths from Task 3 this luminaire stock and sales data can be linked to Power Density Indicator (PDI) and Annual Energy Consumption Indicator (AECI) from EN 13201-5.

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) 400125 **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[126]. The Procedure for the development and revision of EU GPP criteria is explained on the GPP website[127].

For several product groups common GPP criteria[128] 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)[129].
At present the following lighting equipment is covered:

- Indoor Lighting[130]
  Covering "*lamps, luminaires (light fittings) and lighting controls installed inside buildings*" with stated exceptions for specialist lighting.

[125] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2008:0400:FIN:EN:PDF
[126] http://ec.europa.eu/environment/gpp/gpp_criteria_process.htm
[127] http://ec.europa.eu/environment/gpp/gpp_criteria_procedure.htm
[128] http://ec.europa.eu/environment/gpp/eu_gpp_criteria_en.htm
[129] http://ec.europa.eu/environment/gpp/gpp_criteria_wp.htm
[130] http://ec.europa.eu/environment/gpp/pdf/criteria/indoor_lighting.pdf

- Street Lighting and Traffic Signals[131]
  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
- 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**.

[131] http://ec.europa.eu/environment/gpp/pdf/criteria/street_lighting.pdf

- 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 overview of GPP good practice cases are listed on the Commission's website[132] 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[133]. 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 2-4). 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).

[132] http://ec.europa.eu/environment/gpp/case_group_en.htm
[133] http://ec.europa.eu/environment/gpp/pdf/criteria/indoor_lighting.pdf

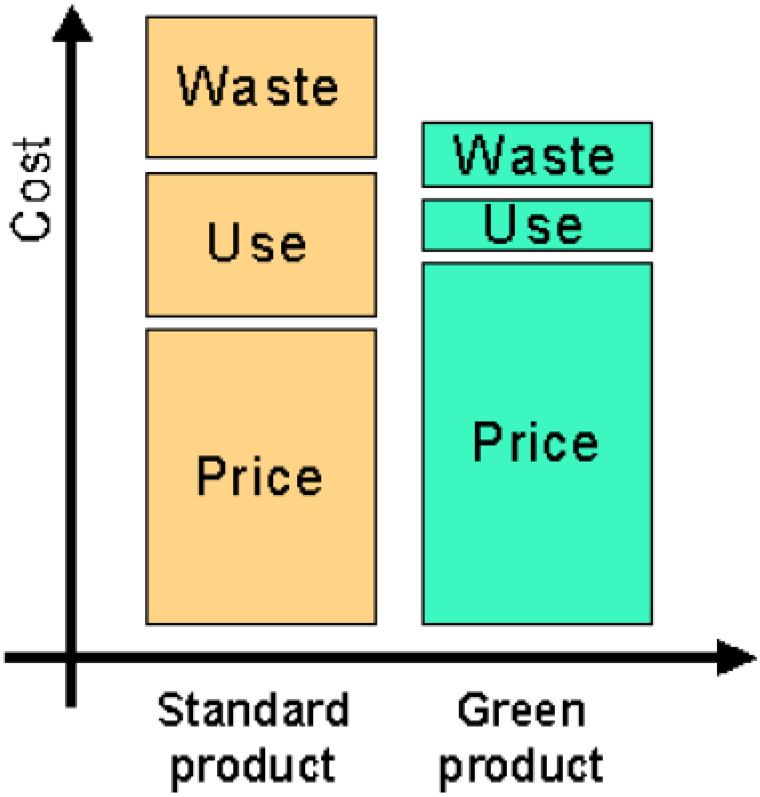

Figure 2-4: Influence of use and End of Life costs on the total costs (Source: EC, GPP training toolkit, module 1 'managing GPP implementation – LCC factsheet', 2008)

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.

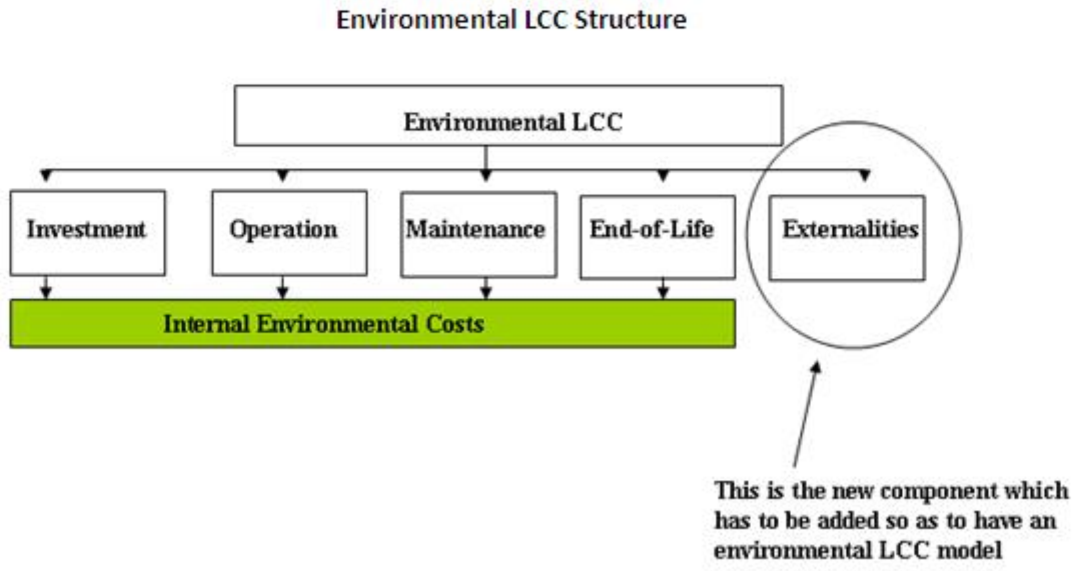

Figure 2-5: Environmental LCC structure (Source: European Commission Life cycle costing web page[134], consulted on 25 November 2015)

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[135]

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[136].

The **SMART-SPP project[137]** developed and tested a tool for public authorities to assess LCC and CO_2 emissions and to compare bids for products using electricity. It[138] is available to download in four languages.

[134] http://ec.europa.eu/environment/gpp/lcc.htm
[135] http://www.procuraplus.org/
[136] http://www.msr.se/en/green_procurement/LCC/
[137] http://www.smart-spp.eu

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[139].

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

.
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 mark up cost for refined lighting design works will be discussed in this section.
The average hourly rates in the EU28 are shown in Table 2-15 and are used as the installer's hourly rate or for repairs and maintenance such as lamp replacement or cleaning.

[138] http://www.smart-spp.eu/guidance
[139] http://ec.europa.eu/environment/gpp/pdf/Webinar_LCC_June2015.pdf

Table 2-15 hourly rates in EU-28[140]

	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%

[140] Labour costs in the EU28, Eurostat news release 49/2014, 27 March 2014

Several sources publish typical construction cost reference data[141], [142] for cost engineering and construction project budget estimates.
One source contained detailed cost data for the technical building system[143]. The relevant cost data for a typical 6-8 storey office building in the Netherlands is included in Table 2-16. From this table it is also possible to deduct the additional cost for having a refined design which is interesting for later task in modelling the extra design costs for design optimisation. From this table it can be concluded that a standard project will have a typical mark up for design and engineering consultants of 4,75 % (basic construction project in Table 2-16) while a more ambitious and refined design will have 7,75 % mark up (refined construction project in Table 2-16). Therefore a more ambitious optimised design and follow up will typically have 3 % more mark up. For the purpose of this study this extra design mark-up cost can be converted to cost per m² based on the typical cost per m² of the electrical building installation(e.g. 171 euro/m²) minus cabling (31 euro/m²) and wall outlets (assumed 6 euro/m²). Therefore a typical design and engineering mark-up is 6,4 euro/m² that can run up to 10,4 euro/m² for an optimised design and project follow up. **This means that the extra cost for design optimisation, detailed specification and project follow up by a professional lighting designer can be modelled with adding 4 euro per m² as an estimated extra cost.**
According to the International Association of Lighting Designers (IALD[144]), the share dedicated to lighting design represents between 2% and 15% of the lighting system element of the total project cost. Hence the 7,75 % from Table 2-16 is in between this range from 2 to 15 % found in the survey and therefore confirms that validity of the previous cost assumptions related to the project cost. This wide variance is explained by the range of services that may be included in the lighting design, the varied complexity of projects, differences in lighting design markets among EU Member States as well as tariff ranges among practitioners. The upper range of fees (15% of the total project cost) reflects costs related to smaller scale projects in the 30 000 to 100,000 euros range.This is due to additional work and expertise required to deliver lighting design schemes which are more energy efficient as a result of well-considered light distribution and lighting controls but also to the administrative burden of compliance with existing regulations.The added value of professional lighting design, compared to its relatively low cost, is enormous. Professionally designed lighting installations can achieve the following: energy savings, lighting quality, brand identity, desired atmosphere, customer attraction and task efficiency.
It should be noted that this cost can be much higher for projects with particular lighting design requirements and lower for repetitive common construction designs. As a consequence, there is also a minimum project cost projects and therefore smaller projects can become uneconomical (e.g. < 500 m²).
Taking the spreading of this survey into account **in a worst case cost sensitivy analysis** could be done with a mark up that is almost twice as large (1,93 =15%/7.75%) or **8 euro per m² extra cost.**
Note that today the lighting design is often done by the sales support office of the luminaire manufacturer, in this case it is included in the price of the luminaire and its sales overhead cost.

[141] http://www.bouwkostenkompas.nl/,
[142] http://constructioncosts.eu/
[143] kengetallenkompas 'installaties', 2012, www.bouwkostenkompas.nl
[144] https://www.iald.org/ data communicated to VITO in October 2016

Table 2-16 Typical project cost data including design calculations

Reference dimensional data related to electrical systems				
	m^2 per light point	4,5	m^2	
	m^2per wall socket	4,8	m^2	
overall costs				
	electrical technical building installation	103	euro/m^2	low cost building solution
		171	euro/m^2	low energy building& LED lighting& BACS
	total technical building installation	307	euro/m^2	low cost building solution
		392	euro/m^2	low energy building& LED lighting& BACS
element of the building system costs				
	Energy cabling cost installed	31	euro/m^2	
	LFL luminaire magnetic ballast	127	euro/item	
	LFL luminaire HF electonic	157	euro/item	
	LFL luminaire HF electronic dimmable	198	euro/item	
mark up costs for consultants & engineering for technical installations				
	general project description	1,15	%	basic construction project
	general calculation	1,10	%	
	functional specs & drawings	1,50	%	
	meetings	1,00	%	
	total	4,75	%	
	detailed project definition and drawings	1,40	%	refined construction project
	detailed calculations	2,60	%	
	complete tender specification&drawings	2,00	%	
	meetings and follow up	1,75	%	
	total	7,75	%	

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.

2.4.3 Electricity prices and financial rates

Electricity prices and financial rates are already defined in MELISA, consult therefore the light source study.

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 areas, manufacturing areas, sanitary 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 and lack of budget for energy efficient lighting systems can provide an incentive or added value not only for energy service companies (ESCO's)[145] but also producers when they combine technical knowledgde with financial capacities. They could become a one-stop shop including lighting systems that enable builders, developers, owners, operators and occupants of buildings to purchase energy efficient light. Lighting producers and/or ESCO's might be well placed to offer a single-point access to a full range of services from audits, design, financing, installation, operation, repair and end-of contract management of the installation (circular economy[146] contracting).

Many long term(>2y) warranties on LED luminaire performance parameters (F_{LS}, F_{LM}, Tc, CRI,..) or abrubt failures are often unclear and limited in time compared to the return on investment period. As a consequence such an ESCO contract that includes repair and maintenance can be an interesting procurement option compared to an extended product performance warranty.

In addition to ESCO already also some larger lighting manufacturers with vertical integration are currently providing lighting systems on a per lumen hour basis. This is more common in street and road lighting than building lighting.

[145] Role of ESCO's see: IAE Energy Efficiency Market Report 2014 (EEMR 2015), www.iea.org

[146] http://ec.europa.eu/environment/circular-economy/index_en.htm

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 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 designs or applications used in those studies are reused here. Moreover, based on the Task 2 market data and in consultation with stakeholders new Reference Applications(RA) were defined to cover a more representative set of EU non-residential indoor lighting applications. they are:

- A cellular office with ceiling mounted luminaires (cellular ceiling mounted);
- A cellular office with suspended luminaires (cellular suspended);
- An open plan office with ceiling mounted luminaires (open ceiling mounted);
- An open plan office with suspended luminaires (open suspended);
- A corridor in a building (corridor);
- A large Do-it-Yourself store (Large DIY);
- A supermarket(supermarket);
- A large indoor industrial plant (Industry Large);
- A small industry workshop (workhop);
- A large warehouse with optionally some lit racks (warehouse).

For each of these indoor applications different zones(area's) were defined with their minimum lighting design requirements in accordance with EN 12464-1, the main parameters per zone and application are summarized in Table 3-1. For example vertical illuminance requirements(Evert) were added in the supermarket to illuminate properly the shelves and cylindrical illuminance requirements(Ecyl) were added in the offices to increase facial recognition and communication. The main parameters are explained in Task 1. An east window orientation located in Frankfurt is proposed from the set of available locations within EN 15193 to provide EU28 average daylight conditions for the reference or base case lighting applications in Task 4.

Table 3-1 Main design parameters for indoor Reference Applications used in this study

	cellular-ceiling mounted			cellular suspended			open-plan ceiling mounted			
Area code	Task	Surround.	Total	Task	Surround.	Total	desk	storage	Surround.	Total
Area length (window) = LR	2,1		3,6	2,1		3,6		8,68		16,2
Area depth =WR	2,6		5,4	2,6		5,4		3,17		10,8
A (m²) total area	5,46	13,98	19,44	5,46	13,98	19,44	101,70	27,52	45,74	174,96
Share in total area	0,28	0,72	1,00	0,28	0,72	1,00	0,58	0,16	0,26	1,00
height of window (h, Ll)	2,8	2,8		2,8	2,8		2,8	2,8	2,8	
Window orientation	E	E		E	E		E	E	E	
height Task area (h, Ta)	0,8	0,8		0,8	0,8		0,8	0,8	0,8	
distance lum-work plane	2	2		1,5	1,5		2,2	2,2	2,2	
E,m area [lx]	≥500	≥300		≥500	≥300		≥500	≥200	≥300	
U0 (uniformity)	≥0,4	≥0,4		≥0,6	≥0,4		≥0,4	≥0,4	≥0,4	
other relevant parameter (1)	Ecyl		E,m walls	Ecyl		E,m walls	Ecyl			E,m walls
value parameter (1)	≥150		≥75	≥150		≥75	≥150			≥75
other relevant parameter (2)	UGR		E,m ceiling	UGR		E,m ceiling	UGR			E,m ceiling
value parameter (2)	≤19		≥50	≤19		≥50	≤19			113
td (day light h/y)	2250	2250	2250	2250	2250	2250	2250	2250	2250	2250
tn (night time h/y)	250	250	250	250	250	250	250	250	250	250

	open-plan suspended				corridor	Industry large	industry workshop		warehouse	
Area code	desk	storage	Surround.	Total	floor	floor	workfloor		workfloor	racks
Area length (window) = LR		8,68		16,2	1,8	56	28		100	100
Area depth =WR		3,17		10,8	14,4	112	14		70	6
A (m²) total area	101,70	27,52	45,74	174,96	25,92	6272,00	392,00		7000,00	600,00
Share in total area	0,58	0,16	0,26	1,00	1,00	1,00	1,00		1,00	1,00
height of window (h, Ll)	2,8	2,8	2,8		0	12	7		14	14
Window orientation	E	E	E		E	E	E		E	E
height Task area (h, Ta)	0,8	0,8	0,8		0	0,8	0,8		0,8	0
distance lum-work plane	1,7	1,7	1,7		2,8	11	6		14	14
E,m area [lx]	≥500	≥200	≥300			≥200	≥300		≥150	≥150
U0 (uniformity)	≥0,4	≥0,4	≥0,4			≥0,4	≥0,6		≥0,4	≥0,4
other relevant parameter (1)	Ecyl			E,m walls	E,m walls	UGR	UGR	E,m walls	UGR	Evertical
value parameter (1)	≥150			≥75	≥75	≤28	≤25	≥75	≤22	≥200
other relevant parameter (2)	UGR			E,m ceiling	E,m walls			E,m ceiling		Uo
value parameter (2)	≤19			≥50	≥50			≥50		≥0,4
td (day light h/y)	2250	2250	2250	2250	2250	2500	2250	2250	2250	2250
tn (night time h/y)	250	250	250	250	250	1500	250	250	250	250

	largeDIY				supermarket			
Area code	sales	cashier	entrance	Total	sales	cashier	entrance	Total
Area length (window) = LR		29,39		80		10		30
Area depth =WR		9,2		100		8		40
A (m²) total area	7211,00	270,39	518,61	8000,00	955,00	80,00	165,00	1200,00
Share in total area	0,90	0,03	0,06	1,00	0,80	0,07	0,14	1,00
height of window (h, Ll)	6,5	6,5	6,5		4	4	4	
Window orientation	E	E	E		E	E	E	
height Task area (h, Ta)	1,2	1,2	1,2		1,2	0,8	1,2	
distance lum-work plane	5,5	5,5	5,5		2,5	2,5	2,5	
E,m area [lx]	≥300	≥500	≥200		≥300	≥500	≥200	
U0 (uniformity)	≥0,4	≥0,6	≥0,4		≥0,4	≥0,6	≥0,4	
other relevant parameter (1)	Evert			E,m walls	Evert			E,m walls
value parameter (1)	≥300			≥75	≥300			≥75
other relevant parameter (2)		UGR		E,m ceiling		UGR		E,m ceiling
value parameter (2)		≤19		≥50		≤19		≥50
td (day light h/y)	2500	2500	2500	2500	2500	2500	2500	2500
tn (night time h/y)	1500	1500	1500	1500	1500	1500	1500	1500

For road lighting the reference applications were selected in accordance with the market data from Task 2, see Table 2-7, they are:

- A motorway EN 13201 class M2 with 4 lanes total;

- A main or national roads class M3 with two car traffic lanes;
- A secondary rural roads with two car traffic lanes and pedestrian/parking lanes(M4&P4);
- A secondary road with mixed traffic and six lanes(C3);
- A residential area road with mixed traffic class P2 and single sided luminaire arrangement;
- A residential street class P4 and staggered luminaire arrangement;
- A residential street class M5 with two car traffic lanes and pedestrian/parking lanes class P5.

The main design parameters for the road lighting reference applications are summarized in Table 3-2 and were selected in accordance with EN 13201-2.

Table 3-2 Main design parameters for road Reference Applications used in this study

Subcategory for lighting	Motorways	Main or national roads	rural roads or mixed with residential	mixed conflict	mixed traffic	Residential streets P4	Residential streets M5
Typical EN 13201-2 class(2016)	M2	M3	M4(&P4)	C3	P2	P4	M5(&P5)
Typical EN 13201-2 class(2004)	ME2	ME3b	ME4a(&S4)	CE3	S2	S4	ME5(&S5)
EN 13201-5 road profile	A	A	E	B	B	B	E
pole distance[m]	50	45	35	35	35	25	21
average pole hight[m]	15	15	10	10	7	5	7
lanes for car traffic	4	2	2	6	2	2	2
luminaire arrangement	central	single	single	opposite	single	staggered	single
luminaires per pole distance	2	1	1	2	1	1	1
centerbeam[m]	2	0	0	0	0	0	0
width one lane[m]	3,5	3,5	3,5	3	4	5	3,5
emergency lane[m] = Edge Illum. Ratio	3	-	-	-	-	-	-
pedestrian/cycling/parking zones or lanes			2	incl. in lane	incl. in lane	incl. in lane	2
pdestrian/cycling/parking zone width(m)	0	0	1,5	incl. in lane	incl. in lane	incl. in lane	1,5
EN 13201-2							
min. maintained average illuminance[lx]	21,43	14,29	10,71	15	10	5	7,14
Qo	0,07	0,07	0,07	0,07	0,07	0,07	0,07
CIE roadway surface	R3	C2	C2				C2
min. maintained average luminance[Cd/m²]	1,5	1	0,75				0,5
tfull [h/year]	2 000	2000	2 000	2000	2 000	2000	2 000
tred [h/year]	2 000	2000	2 000	2000	2 000	2000	2 000
kred	1	1	1	1	1	1	1

To model the impact of the use-phase energy calculations are proposed in line with standards EN 15193 for indoor lighting and EN 13201-5, see Task 1 that also explains and defines the used parameters herein. In this Task reference design data is included for the selected applications and also potential deviations under real circumstances are discussed that could serve afterwards for sensitivity analysis.

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[147] 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:

- 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[148] 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.

[147] http://www.meerp.eu/
[148] http://www.meerp.eu/

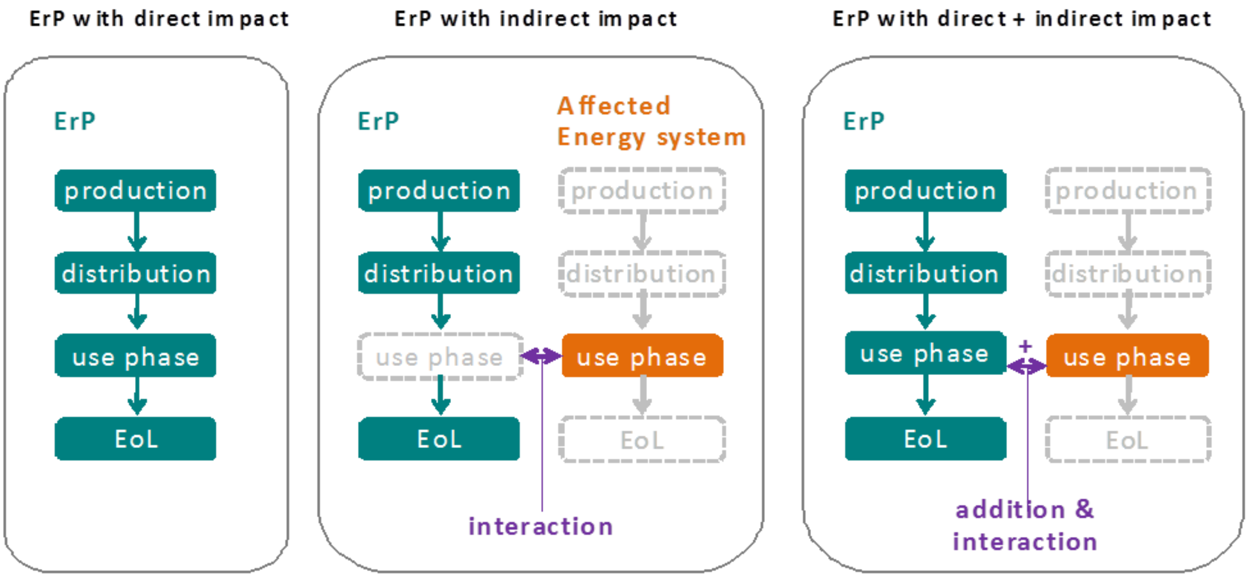

Figure 3-1: Three groups of ErP, distinguished by their impact (source: MEErP 2011 Methodology Part 1).

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[149]).

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 applications 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. Based on the Task 2 market data and in consultation with stakeholders new reference designs (RD) were defined to cover a more representative set of EU lighting applications.

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3.1.2.1 Indoor reference applications

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

Based on the Task 2 market data and in consultation with stakeholders reference designs (RD) were defined to cover a more representative set of EU non-residential indoor lighting applications. they are :

- Cellular office with ceiling mounted luminaires (cellular ceiling mounted)(Figure 3-2);
- Cellular office with suspended luminaires (cellular suspended)(Figure 3-2);
- Open plan office with ceiling mounted luminaires (open ceiling mounted) that includes a.o. a meeting area with cylindrical illumination requirements for facial recognition(Figure 3-3);
- Open plan office with suspended luminaires (open suspended);
- A corridor in a building (corridor)(Figure 3-3);
- A large Do-it-Yourself store (Large DIY) that includes a.o. vertical illumination requirements for shelves(Figure 3-4);
- A supermarket(supermarket) that includes vertical illumination requirements(Figure 3-4);
- A large indoor industrial plant (Industry Large) with a high ceiling(Figure 3-5);
- A small industry workshop (workhop)(Figure 3-5);
- A large warehouse with optionally some lit racks with vertical illumination requirements(warehouse)(Figure 3-6).

For each of these indoor applications the minimum measurable lighting design requirements were defined in accordance with EN 12464-1, the main parameters including dimensions and surface reflection are summarized in Table 3-1. For all applications it includes E,m (minimum maintained average illuminance), UGR and Uo (uniformity) for different zones within the reference application. For some applications also vertical illuminance requirements(Evert) were added, for example in the supermarket to illuminate properly the shelves. Also cylindrical illuminance requirements(Ecyl) were added in the offices to increase facial recognition and communication. To avoid gloom and to raise adaptation levels and comfort of people in buildings, also minimum requirements for walls(Em>50 lx, Uo≥0,1) ans ceiling (Em>30 lx, Uo≥0,1) were verified for applications were it made sense, i;e. apart from the warehouse. Those lighting design parameters are explained in Task 1.

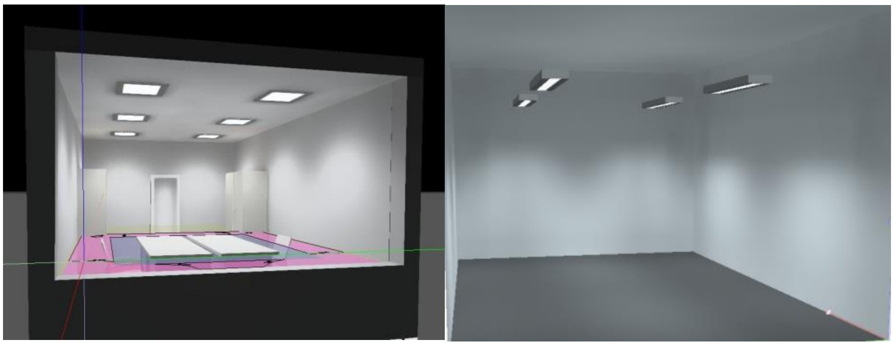

Figure 3-2 Cellular office with ceiling mounted(left) and suspended(right) luminaires reference application

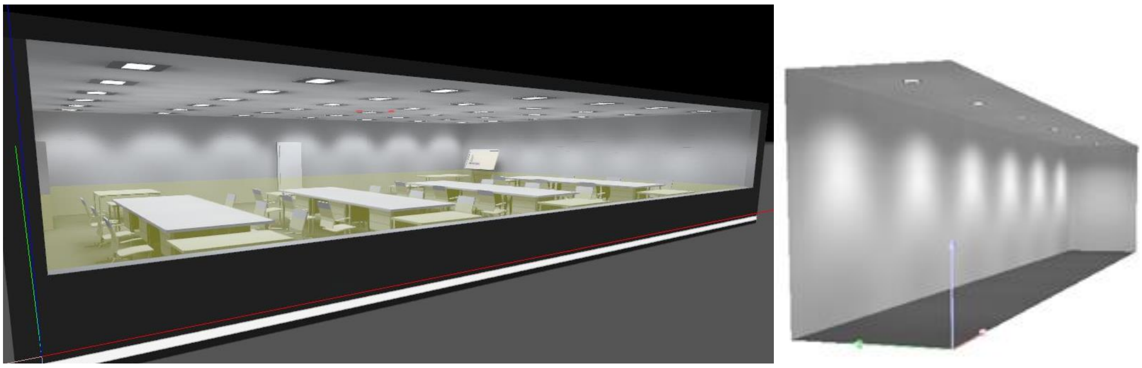

Figure 3-3 Open plan office with different taks zones (left) and corridor (right) reference application

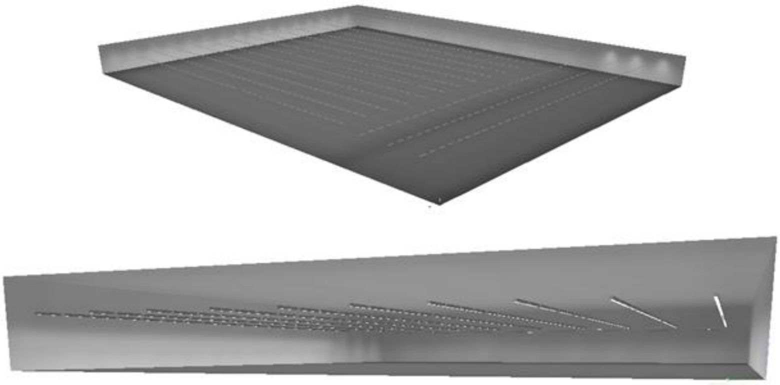

Figure 3-4 A large Do-it-Yourself(top) store and a supermarket(bottom) reference application

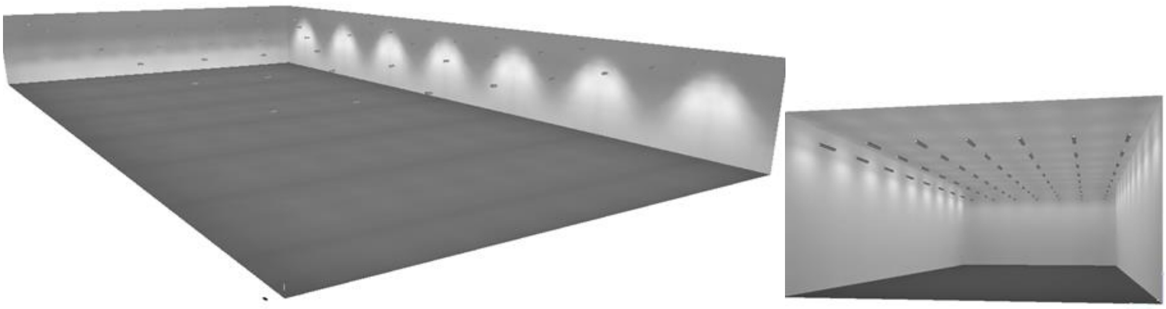

Figure 3-5 A large indoor industrial plant(left) and a small workshop(right) reference application

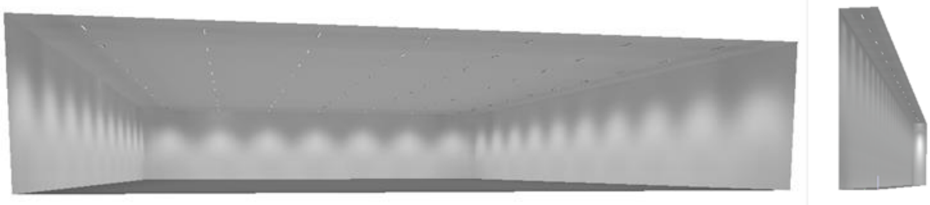

Figure 3-6 A large warehouse(left) with optionally some lit racks(right) reference application

3.1.2.2 Outdoor road lighting reference applications

Based on the Task 2 market data, and in consultation with stakeholders, reference roads were defined to cover a more representative set of EU road lighting applications. they are:

- Motorway EN 13201 class M2 with 4 lanes total, center beam and emergency lane (Figure 3-7);
- Main or national roads EN 13201 class M3 with two car traffic lanes(Figure 3-7);
- Secondary rural roads EN 13201 class M4 with two car traffic lanes and pedestrian/parking lanes class P4(Figure 3-8);
- Secondary road with mixed traffic EN 13201 class C3 with six lanes(Figure 3-8);
- Residential area road with mixed traffic EN 13201 class P2 and single sided luminaire arrangement(Figure 3-9);
- Residential street with mixed traffic EN 13201 class P4 and staggered luminaire arrangement(Figure 3-9);
- Residential street EN 13201 class M5 with two car traffic lanes and pedestrian/parking lanes class P5(Figure 3-9);

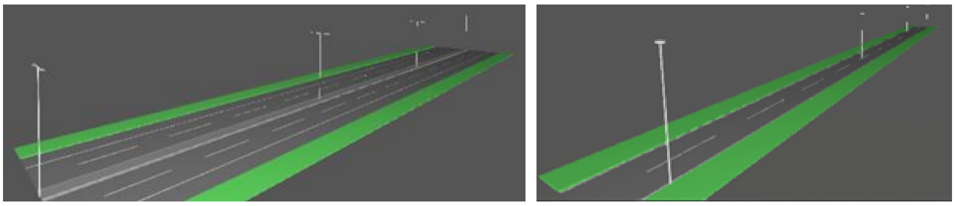

Figure 3-7 Motorway(left) and national road(right) reference application

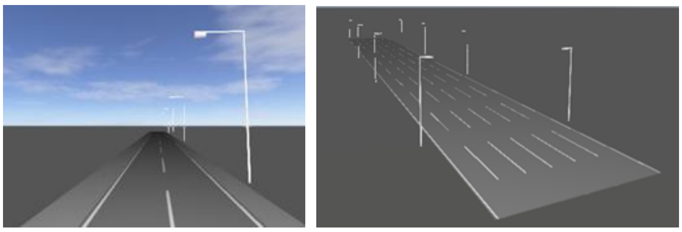

Figure 3-8 Secondary road in rural area (left) and mixed traffic area (right) reference application

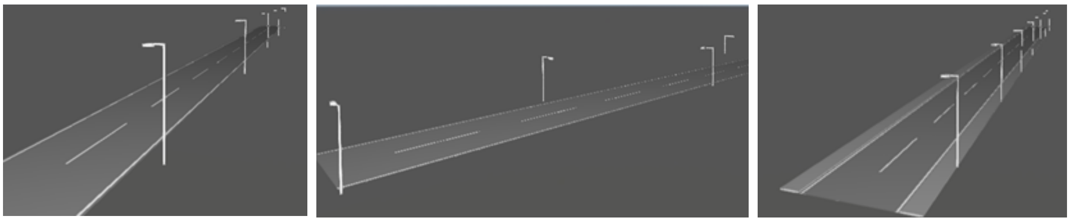

Figure 3-9 Residential road with class P2 lighting requirements(left), with class P4 requirements and staggered luminaire arrangement (centre) and class M5 with pedestrian lanes class P5(right)

For each of these road lighting applications the minimum lighting design requirements were defined in accordance with EN 13201-2. The main parameters for the selected reference applications including dimensions and road surface reflection with there minimum lighitng requirements are summarized in Table 3-2.

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 3-10. The most important parameter is the Lighting Energy Numerical Indicator (LENI, EN 15193) which represents the annual energy consumption(kWh) per square meter.

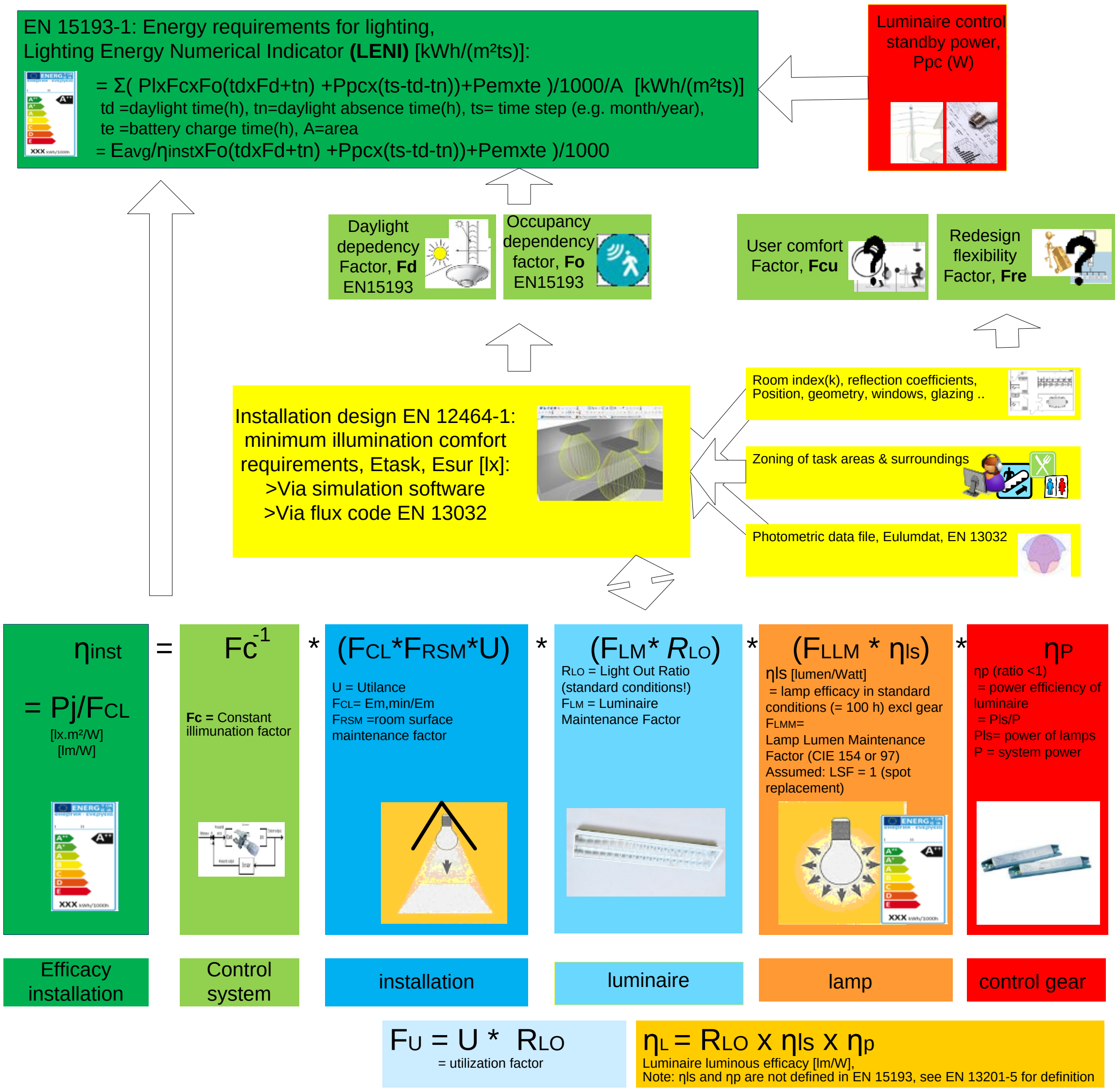

Figure 3-10 Formulas for modelling energy consumption in indoor lighting

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 time (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 15193:2016 proposes the values of td = 2250 h/y and tn = 250 h/y for office buildings, this value is also used for the corridor, industry workshop and warehouse reference applications Note that most hours are during daylight and hence a good daylight design will significantly reduce operating hours, see later section 3.2.1.2.3. Annex B suggests td = 2500 h/y and tn = 1500 h/y for manufacturing factories. This value is used for the large factory reference design. The standard suggests td = 3000 h/y and tn = 2000 h/y for wholesales areas and assumes therefore in total 5000 opening hours per year. This 5000 hours seems high as it is much more than all day open 365 day during 12 h (365x12=4380h). This is considered not to reflect the everage European shop hours and also Task 2 did not confirm high LENI values as realistic, therefore the industry hours are used (i.e. 4000 h).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 3-10 as will be explained in later sections.In practice it is also important that the lighting designer that calculates the LENI value agrees these default hours before the LENI calculation. An overview of used day light time (td) and night time (tn) hours per reference design is in Table 3-1.

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 3-3: Typical occupancy control factors (Foc) (source: EN15193-1)

Systems without automatic presence or absence detection	F_{OC}
Manual On / Off Switch	1,00
Manual On / Off Switch + 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

Table 3-4 Typical absence factors (Fa) for use in this study

room type	**Fa**	**building type**
overall building	0,2	Offices
Cellular 1 p.	0,4	Offices
Cellular 2-6 p.	0,3	Offices
Open>sense 30m²	0	Offices
Open>sense10m²	0,2	Offices
Corridor (dimmed)	0,4	Offices
Assembly hall	0	Manufacturing factory
Storage rack area	0,4	Manufacturing factory
Sales area	0	Wholesale and retail service

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 Occupancy Dependency factor (Fo) can be calculated according to the formulas in EN 15193 from the Occupancy Control factor (Foc) (see Table 3-3) and Absence factor(Fa) (see Table 3-4).

The EN 15193:2016 formulas for calculating Fo from Fa and Foc used are:

If $0{,}0 \leq Fa < 0{,}2$: $Fo = 1 - [(1 - Foc) \times Fa/0{,}2]$

If $0{,}2 \leq Fa < 0{,}9$: $Fo = Foc + 0{,}2 - Fa$

If $0{,}9 \leq Fa \leq 1{,}0$: $Fo = [7 - (10 \times Foc)] \times (Fa - 1)$

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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. In general an appropriate daylight building design will prevent that the lights are on during daylight time (td).

It should be noted that the reviewed version of EN 15193 status 2016 will be used in this study and that the daylight factor calculations are more refined and improved compared to the current EN 15193:2007. This 2016 review takes into account window orientation while this was simplified in 2007. The 2016 review also allows to calculate daylight contribution on a monthly and hourly time step.

Daylight supply in EN 15193:2016 depends on the so-called *Daylight Factor(D)*. This standards classifies daylight availability as a function of the daylight factor, see Table 3-5. 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. Daylight factors can be calculated on different ways, for example with lighting design software (Figure 3-11, Figure 3-12).

Table 3-5 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

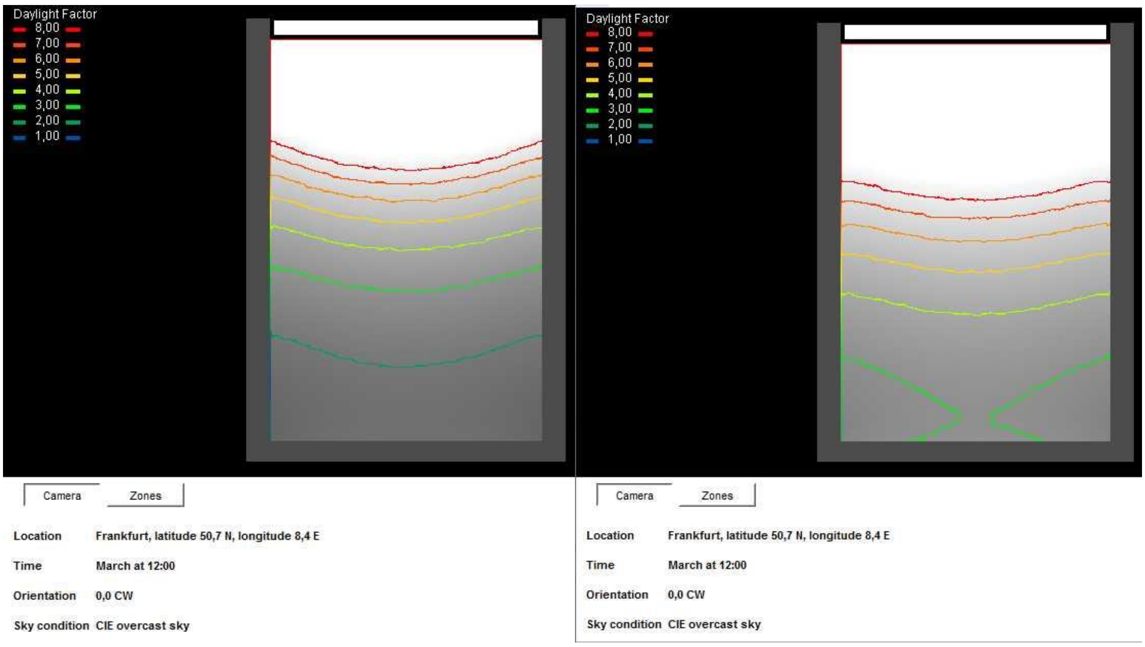

Figure 3-11 Daylight Factor calculations[150], left for a cellular office with standard reflection coefficients (ceiling=0,7; wall=0,5; floor=0,2) and right for bright reflection coefficients ((ceiling=0,84(white matte); wall=0,71 (beige); floor=0,59(linoleum))

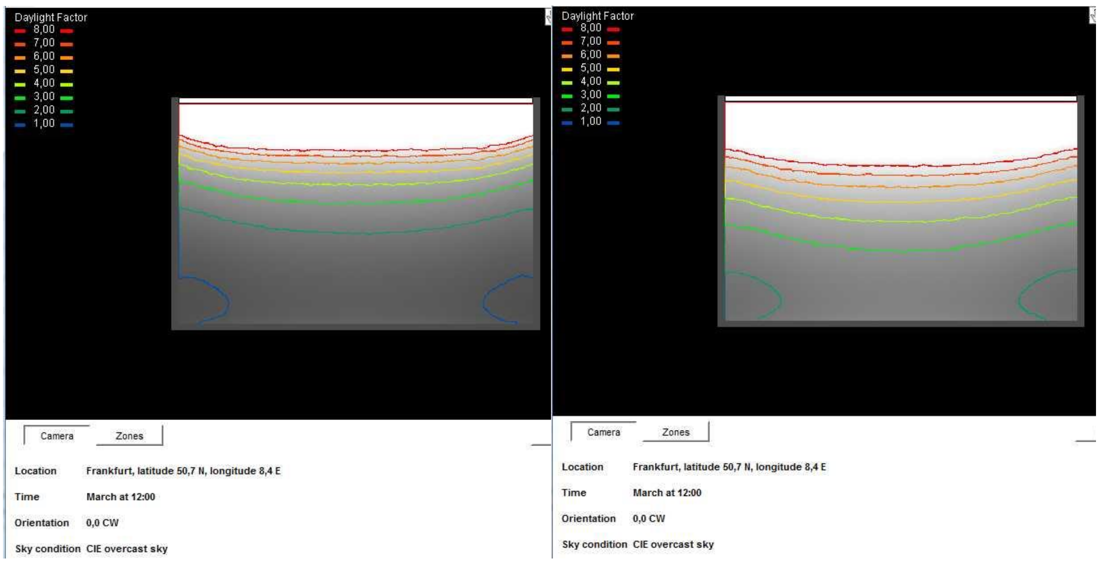

Figure 3-12 Daylight Factor calculations , left for a open plan office with standard reflection coefficients (ceiling=0,7; wall=0,5; floor=0,2) and right for bright reflection coefficients ((ceiling=0,84(white matte); wall=0,71 (beige); floor=0,59(linoleum))

Based on the daylight factor(D) the standard allows to calculate *the daylight supply factor (Fd,s)*. The new EN 15193:2016 version estimates therefore the relative times for non-activated solar/glare protection systems, as a function of the façade

[150] VELUX Daylight Visualizer software (validated with CIE 171:2006), free available at http://www.velux.com/

orientation, the geographic latitude and its ratio of diffuse versus direct light (Table 3-6).
It is important to note that daylight values in prEN15193:2016 depend on geographic location. The prEN 15193:2016 standards gives therefor values for different locations[151] (Athens (GR), Bodø (N), Bratislava (SK), Frankfurt (D), London (GB), Lyon (Fr), Stockholm (S)). In order to produce average results within this study the Frankfurt location will be selected, because it is a central location in Europe. In a sensitivity analysis (if any) also calculations could be done with Athens and Stockholm to see how local daylight availability can impact the average results projected[152]. From Table 3-6 it can also be seen that an East/West orientation is an average orientation in terms of daylight savings compared to South or North, hence an East orientation can be used to estimate average results. Also here, in a sensitivity analysis (if any) an South and North orientation could be used to calculate the potential spreadings on the conclusions.

Table 3-6 Relative times trel,D,SNA,j for non-activated solar radiation and/or glare protection systems, as a function of the façade orientation, the geographic latitude γ and the ratio Hdir/Hglobal (location Frankfurt(D))

orientation	trel,D,SNA
south	0,65
East/West	0,82
North	1,00

Afterwards the standard gives daylight supply factors (Fd,s) for activated and non-activated solar/glare protection systems.
The daylight supply factor for sun shading activated system solutions (annex F of EN 15193:2016) is in Table 3-7. It depends on the types of blind control and the daylight factor wherein the following systems are discrimintated:

- "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
- "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.)

Note that these values are independent of the orientation and location.

Table 3-7 Determination of daylight supply factor($F_{d,s}$) for sun shading activated (source: EN 15193:2016)

Classification of daylight availability

[151] Source: prEN15193 'Table F.2 — Representative locations in Europe with geographical data and luminous exposure'
[152] Note: because this can impact the solar blinds

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**

In order to calculate the daylight supply factor (Fd,s) first also the daylight factor for sunshading not activated should be derived from tables, for example for the Franfurt location on an East/West façade (Table 3-8). Note that these values depend on the geographic location and orientation and the required minimum illuminance in the area. Obviously the more light that is required the lower is the daylight supply factor(Fd,s). Franfurt and an East/West façade can be selected in this study (Task 4) for obtaining an average EU value.

Table 3-8 Determination of daylight supply factor(Fd,s) for sun shading not activated in Frankfurt for orientations East/ West (source EN 15193:2016-

Ēm(illuminance)[lx]	daylight factor(D)	1%	3%	5%	8%
100		0,832	0,909	0,92	0,934
300		0,64	0,837	0,875	0,914
500		0,498	0,753	0,811	0,876
750		0,369	0,656	0,73	0,816

Taking into account the relative time(Table 3-6) and the values for activated and not activated sun shading results for example in Table 3-9.

Table 3-9 Calculated daylight supply factors (Fd,s) for a vertical east/west façade and 500 lx maintained illuminance requirements in Franfurt for use in this study

	Classification of daylight availability			
control type	None	Low	Medium	Strong
MO	**0,41**	**0,64**	**0,70**	**0,77**
Auto	**0,41**	**0,65**	**0,74**	**0,82**
Guided	**0,41**	**0,67**	**0,78**	**0,86**
None	**0,41**	**0,67**	**0,78**	**0,86**
daylight factor(D)	D<2%	2%≤D<4%	4%≤D<6%	D≥6%

For a reference also the more simplified values of EN 15193:2007 are given in Table 3-10.

Table 3-10 Daylight supply factor Fd,s for vertical façades as function of the daylight souce: Table C.2b in EN 15193:2007)

Ēm(illuminance)[lx]	500	500	500	500	300	300	300	300
Daylight availability	None	Low	Medium	Strong	None	Low	Medium	Strong
Athens	0	0,59	0,8	0,9	0	0,8	0,91	0,96
Lyon	0	0,51	0,7	0,82	0	0,7	0,82	0,89
Bratislava	0	0,49	0,68	0,79	0	0,68	0,8	0,87
Frankfurt	0	0,47	0,66	0,77	0	0,66	0,78	0,85
Watford	0	0,45	0,63	0,75	0	0,63	0,76	0,83
Gävle	0	0,38	0,54	0,66	0	0,54	0,67	0,76

Rooflights follow a different calculation method but because an overcast sky supplies 10000 lx compared for example to a minmum required indoor illumination in a factory of 300 lx, it does obviously not require much roofspace to supply sufficient daylight for such an application. Therefore in this study where applicable high daylight supply factors (Fd,s) can be assumed for reference designs where rooflights are possible.

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 3-11. 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 3-11 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
Ēm(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 ($F_{d,s}$) taking into account the relative time for activated glare protection system(if any), 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 EN15193:2016 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, e.g as discussed in see section 3.3.

Calculation and values used for this study:
The Fd factor can be calculated based on the EN 15193:2016 standardwith the calculated for vertical facades Fd,s data supplied in Table 3-9 and the Fd,c data in Table 3-11.
For average European results or so-called base cases in this study the data of Frankfurt(D) on an East façade can be used. In a sensitivity analysis Geographic data from Stockholm (S) and Athens(GR) can be sourced from the standard prEN15193:2016 and also for South and East facades.
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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.

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[153]:LLMF is obtained from the LED luminaire gradual failure fraction, LxBy (IEC 62717): the percentage (y of By) of LED luminaires that fall below the target luminous flux of x percent (x of Lx) at the end of their designated life.

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)/

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

Lx values at B50 will be used (IEC 62717).

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.

LED luminaire gradual failure fraction, LxBy (IEC 62717) refers to the percentage (y of By) of LED luminaires that fall below the target luminous flux of x percent (x of Lx) at the end of their designated life.Gradual lumen loss refers to the LED luminaire or LED module and can occur as a result of a gradual decline in luminous flux or the abrupt failure of individual LEDs in the module. The By value is directly dependent on the L value and denotes how many modules (in per cent) are permitted to fall short of the Lx value.

Research in France[154], [155] 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"[156] gathered information on the frequency of inclusion of cleaning of luminaries during maintenance in offices, as presented in Table 3-12. It revealed that office lighting luminaires were only cleaned regularly in Spanish and private Greek offices.

[154] Enertech, 2004. Technologies de l'information et d'éclairage: Enquêtes de terrain dans 50 batiments de bureaux
[155] Enertech, 2005. Technologies de l'information et d'éclairage: Campagne de mesures dans 49 ensembles de bureaux de la région PACA
[156] DEFU, 2001. Market research on the use of energy efficient lighting in the commercial sector. SAVE report.

Table 3-12: Frequency of inclusion of cleaning of luminaries during maintenance[156]

Frequency %		Total number (n)	No	Yes	n/a[157]
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 FRSM =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.
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. L80B50 is 50000 h, and therefore tables[158] or tools are needed to extrapolate values for the application.

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.*

[157] No answer
[158] Zumbtobel, The Lighting Handbook, p.252, http://www.zumtobel.com/

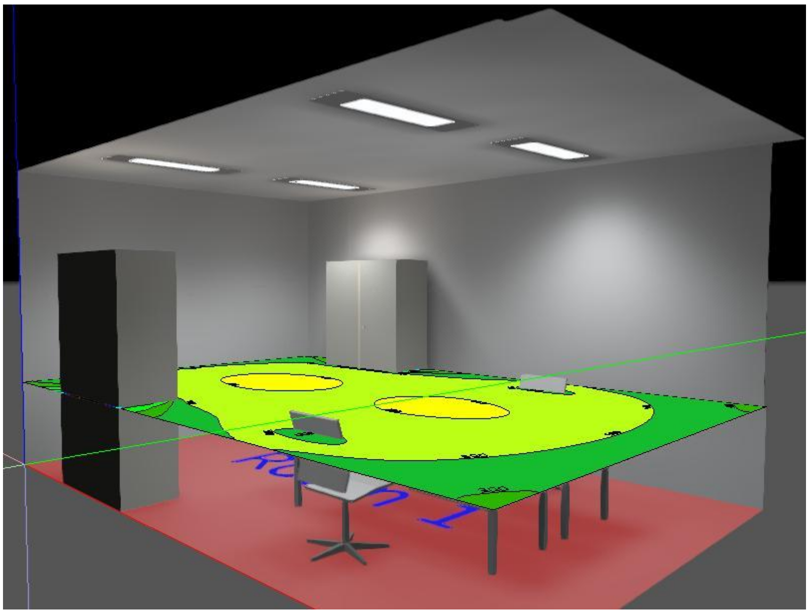

Figure 3-13 Utilance for indoor lighting can be obtained from lighting design calculations[159].

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 3-13) with the following formula:

$U = Em/(\Phi \times A)$

Wherein,
- Φ = Rated luminous flux
- Em = Maintained horizontal illuminance on the task or floor area.
- A = Task or floor area

Background:
<u>Impact of office room area size and light point location</u>
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.

<u>Impact of room surface reflection</u>
The room surface reflection also has an influence on the illumination of the task area. The most common default or typical room reflectance values[160] are included in Table 3-13 below, they can be used for photometric calculations.

[159] Simulation done by Dialux Evo: www.dial.de
[160] Fördergemeinschaft Gutes Licht. Heft 04 Gutes Licht für Büros und Verwaltungsgebäude, ISBN 3-926 193-04-02

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 3-13. 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 3-13 are sourced from Table 3-7 and based on reference data from daylight calculation software[150]. It should be noted that lighting design software such as Dialux (4.12) and/or reference calculations in standard EN 15193 use by default (70/50/20). These reflection coefficient (70/50/20) are historical but office environments are today cleaner (=non smoking area) and materials, especially ceiling tiles, tend to be lighter. Therefore In general current modern offices may be assumed to have reflectances of ceiling: 80% vs 70 % and walls 60% vs 50%.

Table 3-13: 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 [160]. 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[161] 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 section 4.1.1. 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 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

[161] Licht.de: Guide to DIN EN 12464-1, ISBN-No. PDF edition (English) 978-3-926193-89-6

reference cellular application office defined in section 4.1.1, we will therefore assume two office workers.

What are typical dimensions of a large office room or *open plan office?*
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 section 4.1.1 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.
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.

Meaning of Utilance with vertical illuminance requirements and limitations of Utilance as an optimisation parameter:
The reference surface in indoor lighting (EN 12464-1) is usually the horizontal floor area and therefore this will be used as an indicative value in this study. Please note that similarly lighting design software such as Dialux outputs the equivalent lighting power density indication [W/(lx.m²)]. Note that the Utilance is an indicative parameter only and often other design criteria are involved that can limit the optimisation, for example vertical illuminance requirements for supermarket shelves (see reference designs);

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**(**Fcl** is defined.*

Approach:
The correction factor for over-lighting, Fcl=C_L=Em,min/Em as defined in Task 1.

Background:
Selecting the correct number of luminaires to closely match the minimum required illumination:
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.
Over-dimensioning task areas with high illuminance requirements:
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.
In the reference designs the surrounding and the task area is precisely defined, hence these improvement scenarios can be calculated accordingly.
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[162] (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[149]. 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), hence this temperature effect is already included and therefore this study will not use BMF corrections.
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 [163]. The most commonly used active electronic PFC topologies are independent of the line voltage[164].
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

[162] http://ecodesign-lightsources.eu/
[163] 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
[164] Garcia, (2003), Single phase power factor correction: a survey, IEEE Transactions on Power Electronics, volume 18, issue 3, May 2003.

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[149].

Low Power factor impact:

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[165]. 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[166]. 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 [163]. As a consequence electronic ballasts (of > 25 W) with power factor compensation outperform magnetic ballasts.

Conclusions and values used for this study:

It is proposed to neglect within this study the losses associated with deviations in the operating conditions of luminaires from those specified in the standard conditions discussed before, because more precise data and also the evidence of their significance is missing. Morever taking these effects into account is not common practice and .

according to the experience of the lighting industry[167] these effects can be safely ignored and they would useless complicate this study. Therefore it is also assumed in this study that the products are used according to their specified environmental conditions (e.g. ambient temperature, line voltage,..).

[165] 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.

[166] IESNA, 1995. Lighting Handbook, Eighth Edition, ISBN 0-87995-102-8, p.215

[167] See comments from Lighting Europe in the complementary project report.

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 13201-5

Formulas are also introduced in Task 1, see Figure 1-2 and the relevant part is included in Figure 3-14 . There are two parameters, the Annual Energy Consumption Indicator (DE = AECI,rEN 13201-5) which represents the annual energy consumption(kWh) per square meter and the lighting power density (Dp = PDI). but in annex it contains also the installation efficacy(ηinst)(lm/w) that can be calculated from the lighting power density (D_P). It is important to understand that the AECI shouldn't be used alone, but next to the other indicator PDI (Power Density Indicator) also mentioned in EN 13201-5. Note in this value the savings from dimming can be included. The difference is that AECI includes dimming while PDI not as illustrated in the figure.

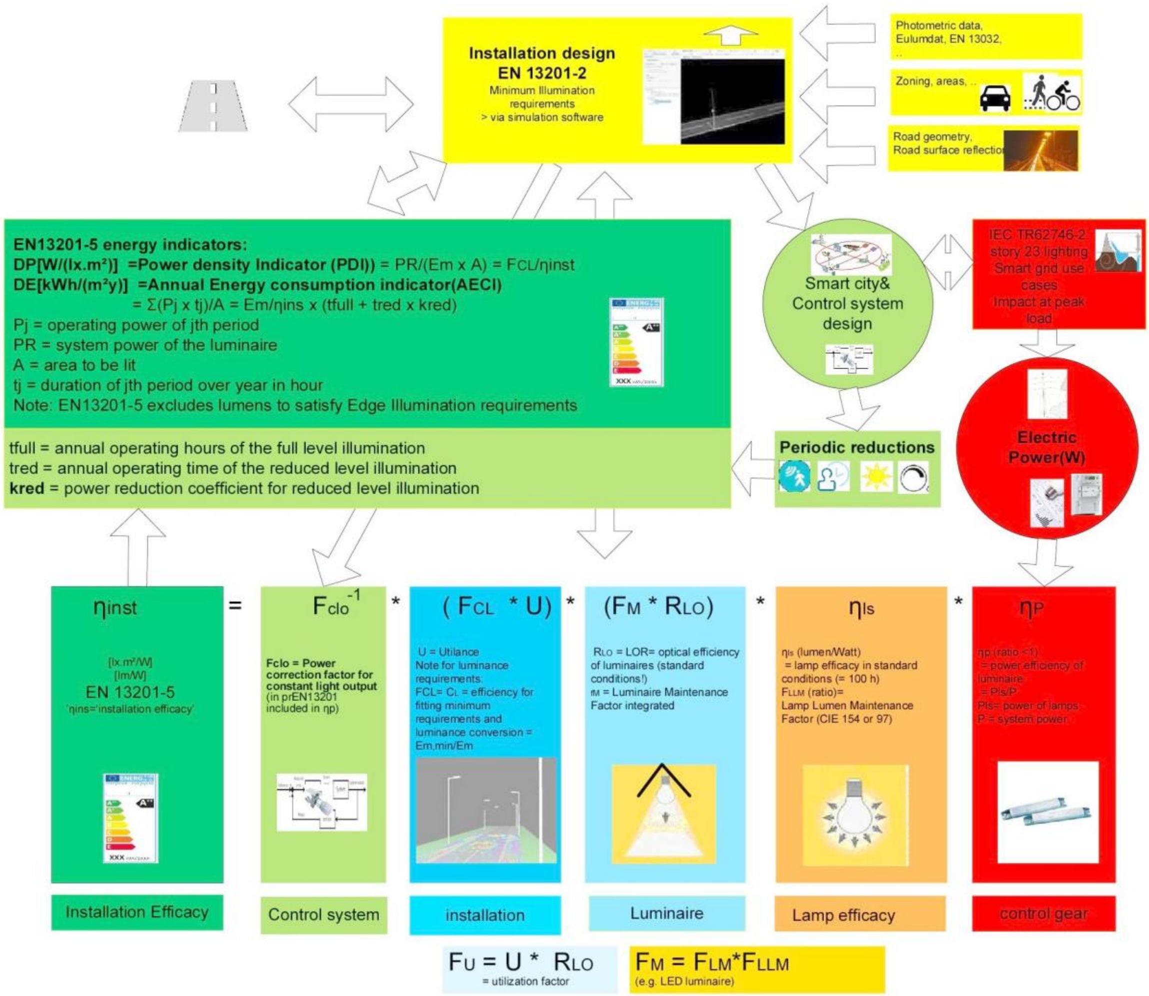

Figure 3-14 Formulas for modelling energy consumption in road lighting lighting

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[168].
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:

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[168] Narisada K. & D. Schreuder (2004), Light pollution handbook., Springer verlag 2004, ISBN 1-4020-2665-X

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.

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 (F_{LM}, F_{LLM}, F_{RSM})

See section 3.2.1.3 for definition and approach.

Additional background for road lighting:
The amount of dirt and water getting inside the luminaire should be reduced as much as possible and the luminaire's resistance to heat should be optimised as well. The resistance of the luminaire against dirt and water getting inside is described by the ingress protection (IP rating). It describes how well the luminaire performs against these environmental factors, including when they are repeatedly opened for lamp or control gear replacement.
The guide CIE 154:2003 on 'Maintenance of Outdoor Lighting Systems' contains F_{LM} factors and cleaning schedules, for example:

- Open luminaires (IP2x): FLM = 0.5, medium pollution, 2 year cleaning cycle
- Closed luminaires (IP5x): FLM = 0.86, medium pollution, 2 year cleaning cycle
- Closed luminaires (IP6x): FLM = 0.89, medium pollution, 2 year cleaning cycle

A study in the UK[169] however showed that these CIE 154:2003 values are conservative and can be improved (see Table 3-14). That study proposes to use pole height in combination with environmental zones of guide CIE 150 (with zone E1/E2 natural/rural

[169] CSS, (2007.): A. Sanders, A. Scott, 'Review of luminaire maintenance factors', CSS-street lighting project SL3/2007

surroundings and zone E3/E4 suburban/urban surroundings). Using these reviewed values will reduce over-lighting and over-dimensioning of new installations.
Cleaning of road lighting luminaires is often combined with group replacement of lamps.

Table 3-14 Reviewed luminaire maintenance factors for IP6x road lighting luminaires[169]

Cleaning cycle	**12 months**	**24 months**	**36 months**	**48 months**
Zone and Mounting Height	**FLM**	**FLM**	**FLM**	**FLM**
rural/natural (E1/E2) 6m or less	0.98	0.96	0.95	0.94
rural/natural (E1/E2) >7m	0.98	0.96	0.95	0.94
suburban/urban (E3/E4) 6m or less	0.94	0.92	0.9	0.89
suburban/urban (E3/E4) >7m	0.97	0.96	0.95	0.94

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,

Φ = Rated luminous flux
Em = Maintained illuminance
A = Task Area

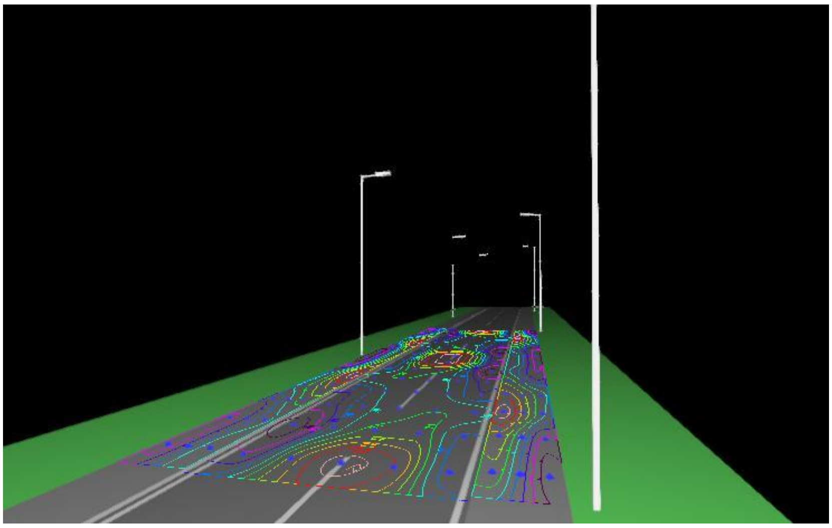

Figure 3-15 Utilance for road lighting can be obtained from lighting design calculations[170].

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 3-16, 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 3-16: More than half of the light is directed to the sky or sea and is wasted

Note: Be aware that the Utilsation Factor for road lighting (UF) is under discussion in CEN/TC 169 for EN 13201-6 on how to apply the UF is under development but there is

[170] Simulation done by Dialux Evo: www.dial.de

not yet a consensus. Therefore the application herein is indicative and might change in the future. The European Commission has published M485 asking to propose a table of energy efficient utilization factors (UF) for different roads (see section1.4.5.3).

Impact from road width:

The road width is an important parameter defining the road surface to be lit.
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: $\bar{L}m = Q_O \times Em$. Typical values for Q0 are given in Table 3-15 and the expert enquiry results in Table 3-16. Please note that real road reflection can vary strongly depending on local conditions (dustiness, wetness, etc.) from -40 % up to 60 %.

Table 3-15: 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 artificial brightener	mostly diffuse
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 3-16: 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[171] (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.

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

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 (yellow-green) according to the definition of the CIE 1931 standard observer[172] as illustrated in Figure 3-17. 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 3-17.

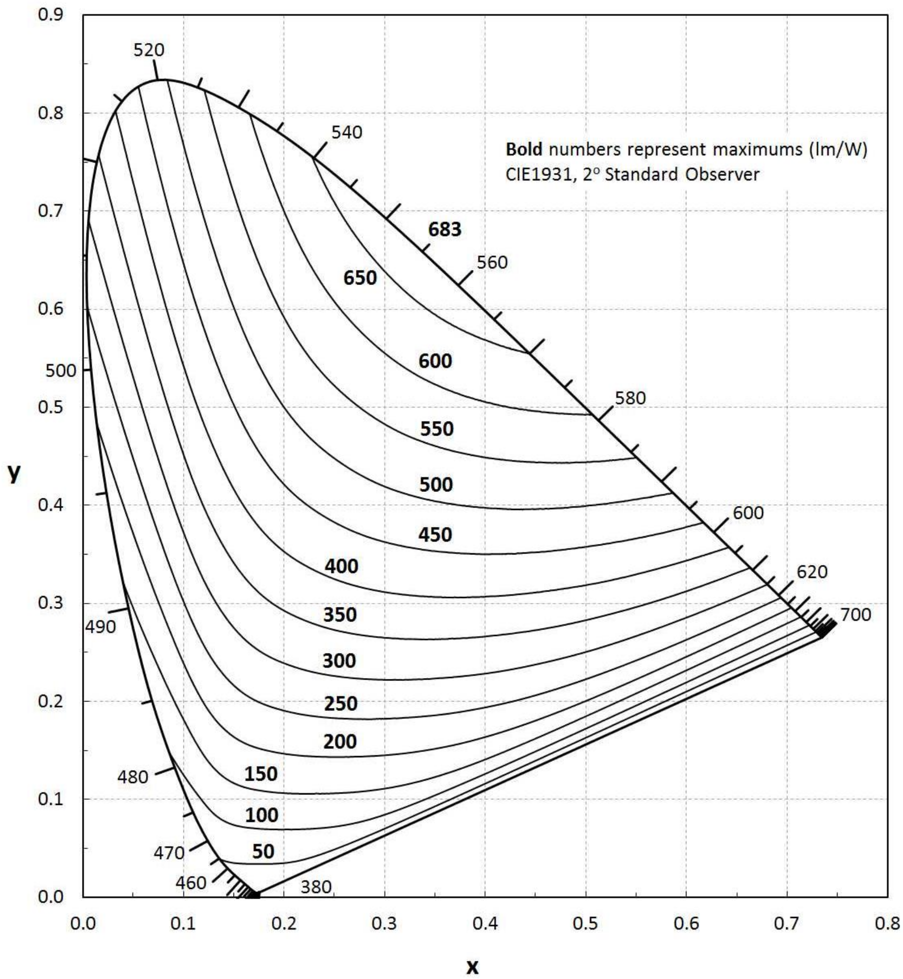

Figure 3-17 Maximum possible luminous efficacy (lumens per watt) shown on CIE 1931 chromaticity diagram (Schelle, 2014[173])

Scotopic vision is the scientific term for human vision "in the dark".

[172] https://en.wikipedia.org/wiki/Luminosity_function
[173] 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

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[172], 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.

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.

The EU MOVE project(Mesopic Optimisation of Visual Efficiency) and IEC TC1-58 have both finished a long time ago. Conclusion of the research on the practical applicability of mesopic photometry is that in areas equipped with road lighting, the user is never adapted so 'deep' into the mesopic region, to make these effects practically relevant. Where it could be relevant, the user still needs to be able to accomplish his foveal eye tasks (those performed while looking directly at something) and these do not profit from a mesopic effect, as there are no rods in the fovea, only cones. Conclusion of the research on the practical applicability of mesopic photometry is that in areas equipped with road lighting, the user is never adapted so 'deep' into the mesopic region, to make these effects practically relevant. .

<u>Temperature:</u>
See section 3.2.2.
<u>Line voltage:</u>
See section 3.2.2.
<u>Lamp voltage:</u>
See section 3.2.2.
<u>Power factor compensating capacitor aging:</u>
See section 3.2.2.
<u>Car headlights:</u>
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. Also consider with car headlamps that on high speed roads the lit distance is generally less than the stopping distance without additional roadlighting. On slower roads the mixed traffic can mean some users are not in a car and do not benefit from having headlamps. Therefore it is proposed to neglect this.

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.

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

Heat replacement effect means that the waste heat produced with by the appliance or lighting contributes to the internal heat gain of the building and hence lowers the energy bill for heating the building. For example, the waste heat from a television set contributes to the heating in the winter and lowers therefore the energy bill of the heating system. This means that in part the energy savings are offset because there is an increased need for heating in the heating season. Nevertheless, the opposite effect also exist meaning that more cooling will be needed in the summer due to increased waste heat for inefficient equipment, see section 3.3.2.
A continuous heat demand would be typical for a poorly insulated building and non-air tight building in a Nordic or cold climate, which is certainly not a future trend[174] given the European Near Zero-Energy Building strategy[175] (NZEB). Due to their better insulation and airtightness these NZEB buildings will balance more between coping with overheating and cooling demand versus heat demand. As a conclusion, an extreme situation for a non-residential building where all waste heat from lighting can contribute to heat replacement is generally spoken in Europe unlikely.
Heat from lighting is mostly generated at the ceiling where air is often evacuated for ventilation and therefore also it would be an inefficient heating method in many applications.
Also when waste heat from lighting contributes to heat replacement it is an inefficient method of electrical heating because heat can be generated more efficiently with a heat pump[176]. Heat pumps typically need 1kW electricity to generate 4 kW heat. Note that most heat pumps can work bidirectional and heat or cool.
.

3.3.2 Impact on the cooling loads in buildings

Waste heat from lighting or appliances can significantly contribute to an increased cooling load for non-residential buildings. This means that installing inefficient lighting in buildings with cooling requirements will further increase the cost of the cooling system by increasing the cooling system load.
This can be for example the case in dense office buildings with a high amount of internal heat sources (people, computers, lighting, ..). To correct the energy balance in such a system and keep the room temperature under control a cooling system will be needed.
Cooling needs are also typical for more southern European climates due to the outdoor temperature. In central and northern European climates cooling needs in non-residential buildings will also become more likely due to better insulated buildings[177], especially in a Near Zero Energy Building strategy[178].
How much do lighting losses increase the cooling load is related to the working principle of a heat pump[179]. Here again typically only 25 % or 1kW electricity can generate 4 kW cooling. This would mean that the calculated energy demand for lighting(LENI) will increase the total electricity demand of a building with 125 % of the LENI value when all year cooling is needed.
Note that building cooling needs often coincide with solar radiation and hence this electricity could be generated sustainable locally with photovoltaics. However photovoltaics are expensive systems (euro/kW) and a cost effective building design strategy could remain to size down the LENI (kWh/m²) as much as possible.

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[174] https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings
[175] https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings
[176] http://www.ehpa.org/technology/key-facts-on-heat-pumps/
[177] https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings/nearly-zero-energy-buildings
[178] https://ec.europa.eu/energy/intelligent/projects/en/projects/zebra2020
[179] http://www.ehpa.org/technology/key-facts-on-heat-pumps/

3.3.3 Conclusion on indirect impact on heating and cooling in buildings

For the average European scenario in Task 4 and 7 it is proposed to neglect the impact on additional cooling loads and heat replacement effects because they are both opposite effects that could compensate each other.
In a sensitivity analysis on the base case(if any) one could consider a Nordic poor insulated building with electrical heating without heat pump. In that case there is most likely no pay back of more efficient lighting systems neither additional energy savings. This could illustrate a potential trivial lighting application case.
Looking to the future trends in building insulation a cooling scenario looks more likely, in that case there will be a leverage effect on the LENI value because of increased cooling loads with LENI. The highest possible impact is 125% LENI when taking the maximum extra cooling loads into account all year long.

Note however that in individual building design the LENI values can be calculated on a monthly basis according to prEN 15193:2016 and hence these effects can and are taken into account in contemporary building design with the calculation tools provided.

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[180].
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 [154],[155].
The SAVE study[181] 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[182] 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.

[180] ATLAS, 2006. http://ec.europa.eu/comm/energy_transport/atlas/htmlu/lightdmarbarr.html
[181] Novem, 1999. Study on European Green Light: Saving potential and best practices in lighting applications and voluntary programmes. SAVE report
[182] 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

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.

Note that for LED luminaires the life time calculation might be different and therefore the typical lifetime of an installation. However for an office an assumed 50,000 hours luminaire life 20 years is approximately correct (2500 h/y x 20 y) and therefore this can be simplified in this study.

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 was common practice[183]. This figure is based on practical experiences and is confirmed by the first responses to our inquiry (Table 3-17). 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 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 was common practice for conventional technology, 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

LED based outdoor luminaires are designed today for 12.5K years (50K hrs.) to 25 years (100K hrs.), therefore reducing the life time to 22,5 years (90K hrs) is more realistic for futher analysis on LED luminaires.

Note that the current trend is to install LED luminaires and that HID lamps are potentially being phase out from the market and are loosing market share[184]. As a consequence when installing an HID road luminaire today (2016) it is unreasonable to expect that competitively priced HID lamps (if any) wil still be available for more than 30 years and assuming a life time comparable to LED luminaire makes more sense for HID luminaires today. Therefore in Table 3-17 new sales luminaire values have been reduced.

Conclusion:

[183] Lot 9 preparatory study on street lighting (2007): http://www.eup4light.net/default.asp?WebpageId=33
[184] http://ecodesign-lightsources.eu/

Regarding average installation an economic lifetime of 22,5 years for road lighting luminaires.

Table 3-17: Luminaire life time for road lighting

	Road class M			Road class C			Road class P		
	min.	avg.	max	min.	avg.	max	min.	avg.	max
life time (y) non-LED (stock)	25	30	35	25	30	35	15	30	35
life time (y) non-LED (new sales 2016)	20	22.5	22.5	20	22,5	22.5	15	22,5	22.5
Life time (y) LED	12,5	22.5	25	12,5	22,5	25	12,5	22,5	25

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[180].
The required installation and maintenance time, estimates are included in Table 37 on the basis of experience.

Table 3-18: 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 or repair LED luminaire (t-group)	10 min.
Time required for spot lamp replacement or repair LED luminaire (t-spot)	20 min.
Time required for luminaire cleaning (in addition to time for group lamp replacement) (t- cleaning)	10 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 3-19.

Table 3-19: Estimation of maintenance and installation time parameters

Time required for installing one luminaire (group installation)	20 min.
Time required for lamp replacement or LED module repair (group replacement)	10 min.
Time required for lamp replacement or LED module repair (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[185],[186] 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 abrubt 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):

$$Nb = BFR/1000h \times Nbal$$

Where:
- BFR = ballast failure rate per 1000 h with the ballast tc point @ 70 °C.
- Nbal = number of ballasts per luminaire.

[185] licht.wissen 01 'Lighting with Artificial Light' available from licht.de
[186] 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 but according to the manufacturers[167] 0.1% per 1000hrs seems more realistic and in line with LED driver specs.

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. Of course the opposite is valid too, this is often the case for outdoor luminaires which operate at night at low temperatures.
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 3-20.

Table 3-20: FLLM and FLS 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:

It should be noted that the purpose of this study is not on light sources but on systems, therefore general default values will be introduced in Task 4 in further tasks. For LED typical values of FLLM are 0.9 @ 50K hours indoor and 0,9 @ 90 K hours outdoor in line with the life time of the installation.

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[149].

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

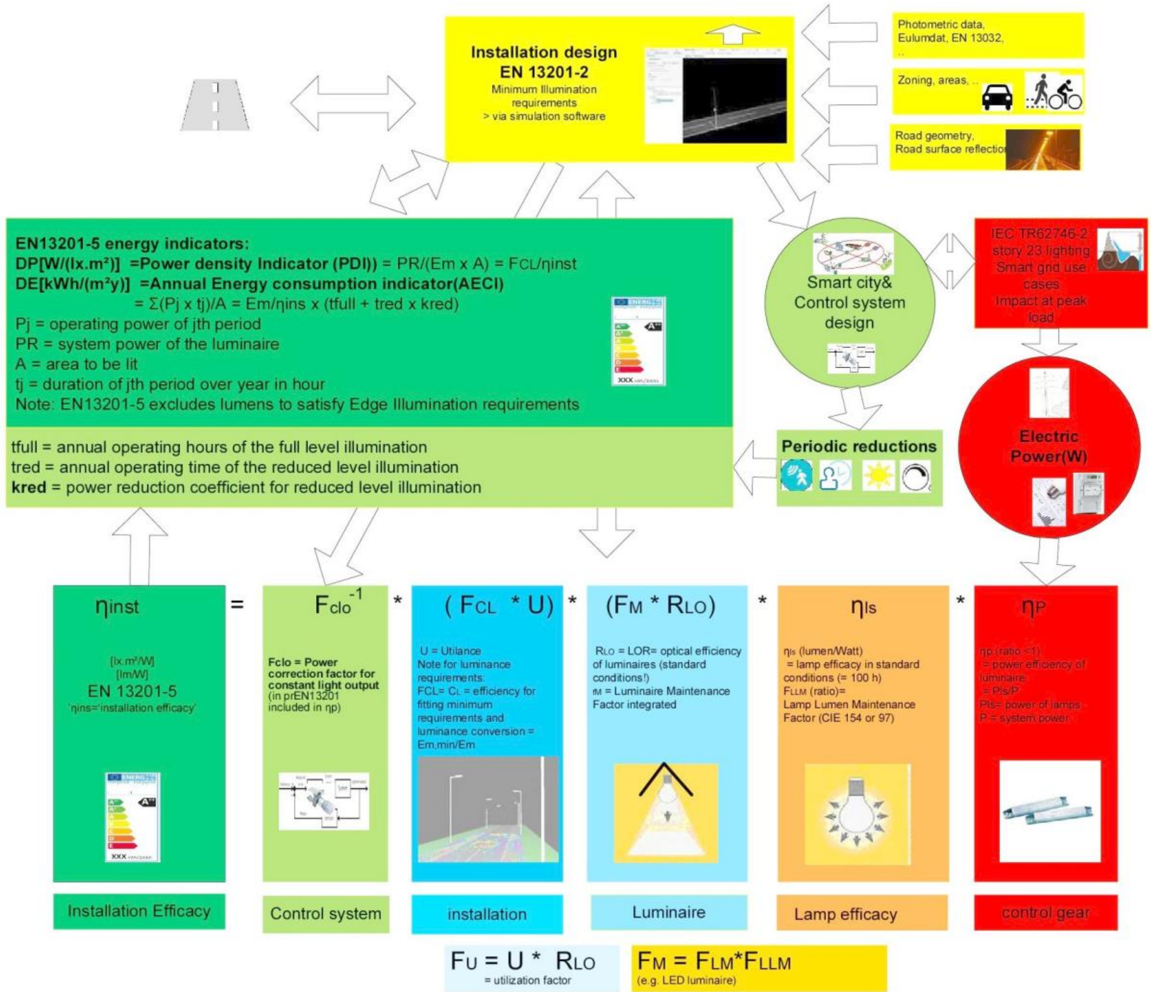


Figure 1-2 and

Figure *1-3*. These standards can provide an objective basis for comparison of alternative designs and therefore yield to more optimised solutions. When Building Automation Control Systems(BACS) are involved users can also rely on standard EN 15193 for further building system integration.

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[187]. 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 3-18. Using this full chain of actors could be an opportunity to increase employment while also having the economic benefits from the energy savings.

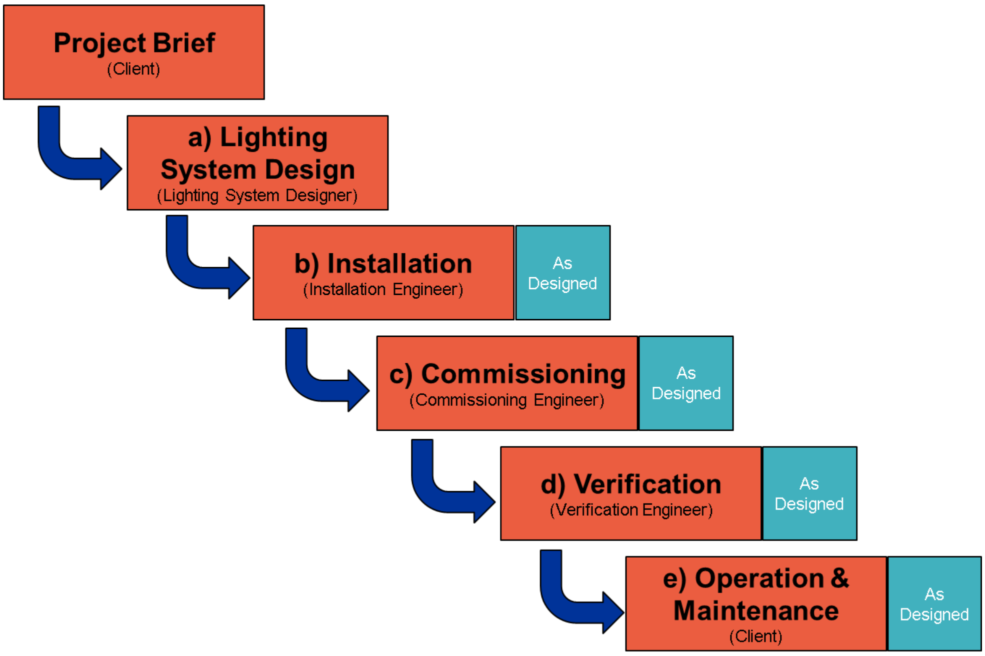


Figure 3-18 Full chain of actors involved from lighting system design until maintenance and operation

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 realised without additional investments.

[187] 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/

Figure 3-19: Street lighting luminaire attached to cables(left) and to electricity distribution (right)

Figure 3-20: 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 3-19 and Figure 3-20). 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 3-21. 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 3-21: 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)[188] 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 3-21) 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'.

[188] IEA, 2006. Light's Labour's Lost: Policies for energy-efficient lighting'

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'.

'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[189],[190],[191]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 3-21), 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'[192].

Figure 3-21: 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[193]. 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

[189] CIE 150 (2003) technical report.
[190] Narisada K. & Schreuder D. (2004) Light pollution handbook., Springer verlag 2004, ISBN 1-4020-2665-X
[191] Steck B. (1997) Zur Einwirkung von Aussenbeleuchtungsanlagen auf nachtaktive Insekten', LiTG-Publikation Nr. 15, ISBN 3-927787-15-9
[192] T. Longscore & C. Rich (2004): 'Ecological light pollution', Frontiers in Ecology and the Environment: Vol. 2, No. 4, pp. 191–198
[193] 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

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".

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 3-3 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 3-23.

Table 3-22 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 3-23 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 3-24 . 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 3-24 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	
	$\bar{L}$ 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

This task does not suggest to further reduce the product scope compared to the proposals in Task 1&2.

3.6.2 Barriers and opportunities

The main opportunity is related to the increased local refined lighting design work and the appropriate follow up process as described in section 3.5.1 The main barrier is the relative long life time of installations as discussed in section 3.4.1.

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. Descriptions are provided of typical products and systems on the market and alternative design options, 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 according to the definition is the MEErP methodoloy[194]:

- '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 B.

All lighting designs are prepared according to minimum measurable EN 12464-1 and/or EN 13201-1 lighting design requirements that are defined per reference design in Task 3.

Summary of task 4:

In this task the current sales base case is compared with different BAT options for eacht of the reference applications that were defined in Task 3. All designs were produced using lighting design software; specifically, Dialux 4.12195 was used for indoor applications and Dialux EVO 6 for road lighting. Most designs were supplied by experienced lighting designers from seven different lighting manufacturers196. The calculated outcomes for indoor lighting are expressed in terms of the Lighting Energy Numerical Indicator (LENI)[kWh/(y.m²)] as defined in EN 15193. Similar results were obtained for outdoor lighting that were calculated in line with the standard EN 13201-5 and that contain the Annual Energy Consumption Indicator (AECI))[kWh/(y.m²)] and the Power Density Indicator (PDI) [W/(lx.m²)]. For all designs detailed subsystem/component parameters are collected in line with the system definitions in Figure 1-2 and

Figure 1-3 of Task 1. This provides insight into what the system design improvement potential is, enables the calculateion of improvement policy scenarios in Task 7 that are independent of the efficacy improvement of the light source itself. Relevant cost data is also presented per design option. From the results it is clear that the high improvement potential is not due only to an increase in light source efficacy but also

[194] http://ec.europa.eu/growth/industry/sustainability/ecodesign/
[195] https://www.dial.de/en/dialux/download/
[196] Members of http://www.lightingeurope.org/

to several other lighting system factors and thus that the improvement potential is a combination of many design options and parameters.
Where applicable the following design options are considered for indoor reference applications:

- 'BC' means the current sales base case, which is a low cost simple design which still satisfies the minimum requirements of EN 12464-1. These designs were created with non-LED products but could of course also be made with comparable LED products, such as retrofit LED tubes. BC could therefore also be considered as a 'basicLED' design, when taking the LED efficacy improvement into account of the light source study. Note that they already satisfy the EN 12464-1 requirements hence in practice significantly worse systems are installed.
- 'BATLED' means the best fit with luminaire optics and layout. It uses LED luminaires for which the optics and layout are carefully selected to yield to the best results.
- 'BATsmart' is the BATLED but combined with the most advanced lighting controls defined in EN 15193.
- 'BATbright' is BATsmart combined with increased surface reflections for reference designs where this is considered possible.
- 'BATday' is BATsmart with the addition of roof lights for increasing the daylight contribution for reference designs where this is considered possible.

For road lighting the following design options were elaborated:

- 'BC' means the current sales base case, which is a low cost simple design which still satisfies the minimum requirements of EN 13201-2. These designs were created with non-LED products but could of course also be made with comparable LED products. Note that they already satisfy the EN 13201-2 requirements and basic design selection rules were applied, hence in practice it is likely that much worse systems are installed.
- 'LEDdesign' means the best fit with precisely selected luminaire optics with LED and design practices as supplied by the participating designers from four different lighting manufacturers[196] .
- 'LEDsmart' is the 'LEDdesign' option but with the best smart controls as defined in EN 13201-5.

All lighting designs are according to minimum measurable EN 12464-1 and/or EN 13201-1 lighting design requirements that are defined per reference design in Task 3.

The LENI results [kWh/y.m²)] obtained for the reference applications defined in Task 3 for various design options are summarised in Figure 4-1. The AECI [kWh/(m².y)] and PDI[W/(lx.m²)] results obtained for the reference roads of Task 4 are summarised in Figure 4-2 and Figure 4-3.

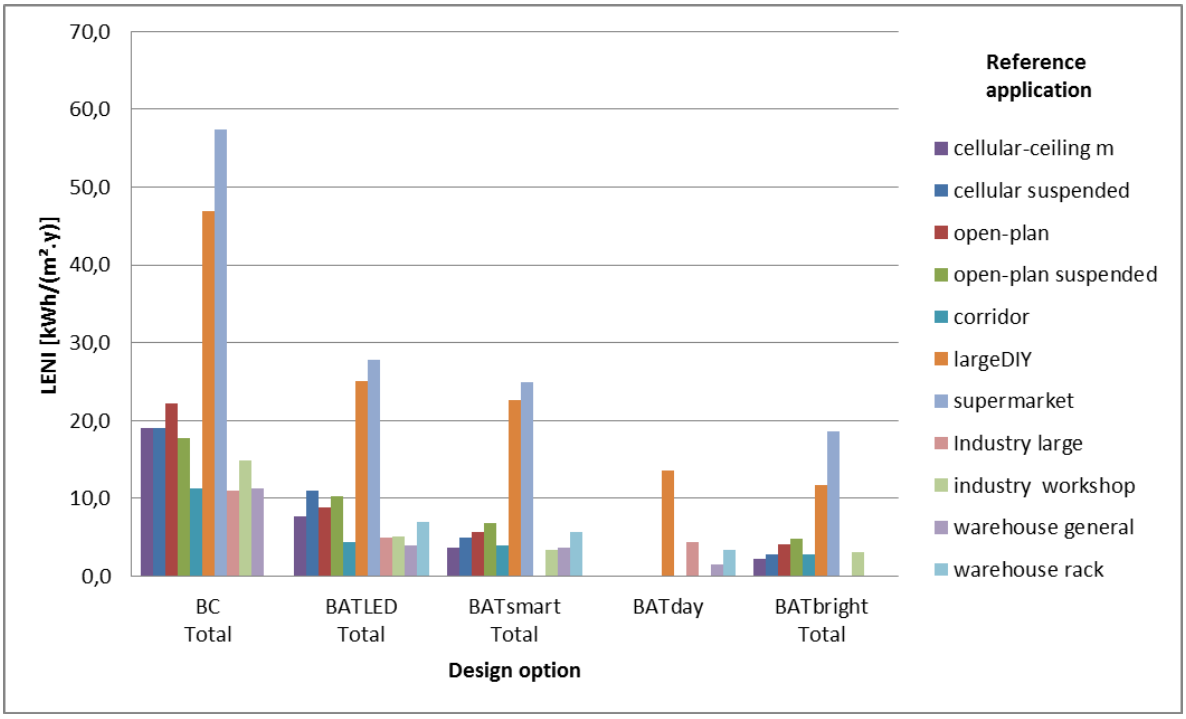


Figure 4-1 Calculated LENI values per reference indoor application for various lighting design options

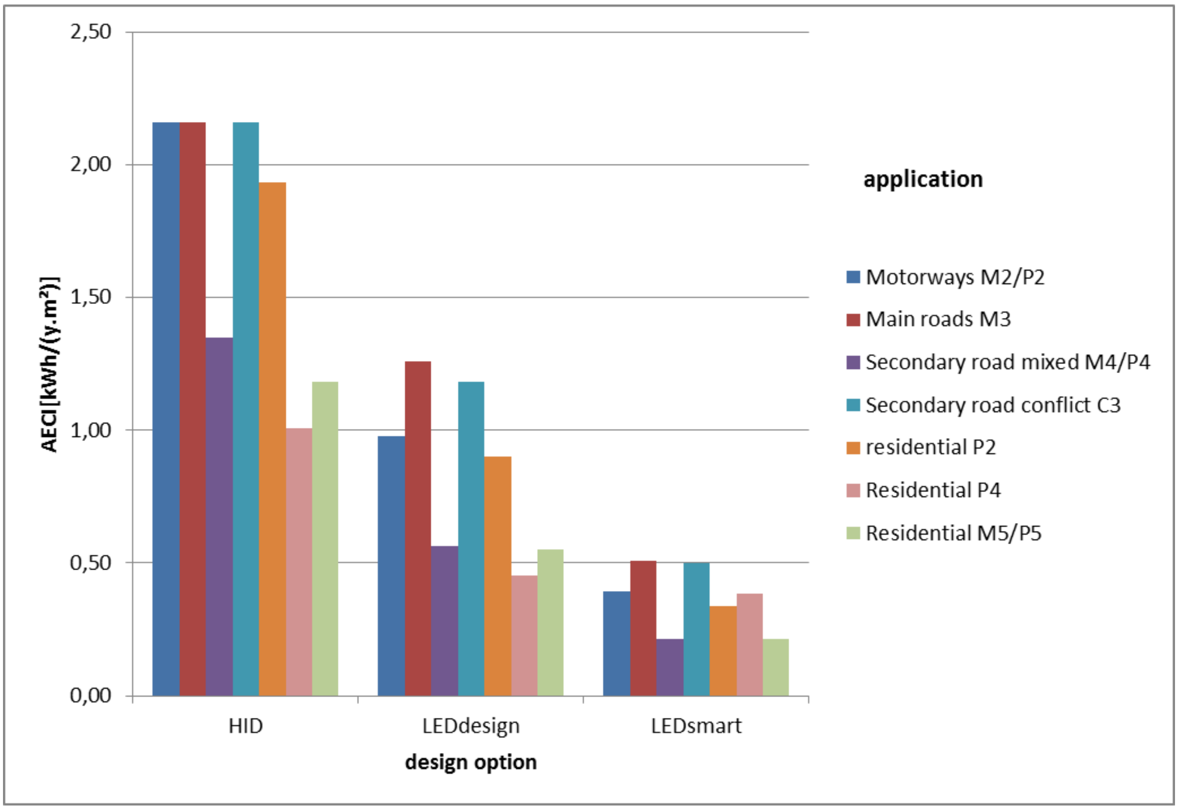


Figure 4-2 Calculated AECI values per reference road for various lighting design options

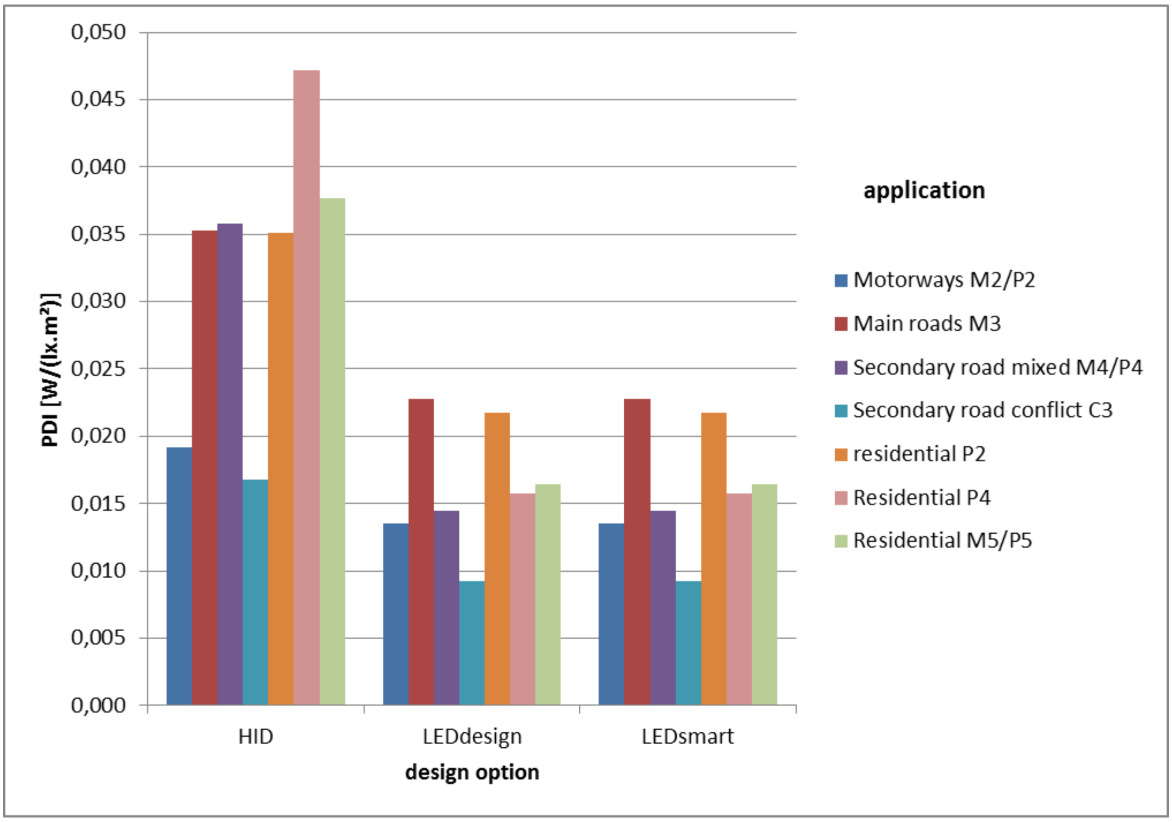


Figure 4-3 Calculated PDI values per reference road for various lighting design options

Apart from improved light source efficacy in road lighting the improvement of Utilance and smart controls also contribute to a large potential AECI reduction. For indoor lighting smart controls, increased surface reflection and to a lesser extent improved utilance contribute to lower potential LENI values. For example in a cellular office LENI could be reduced from 19 kWh/(y.m²) with lamp efficacy of 90 lm/w to 12.6 kWh/(y.m²) with an LED[197] efficacy of 136 lm/W and to 2.2 kWh/(y.m²) with LED and all other design improvements options implemented(extra lighting controls, increased surface reflectance, better lay out planning and optical arrangement). Hence the majority of the reduction in the LENI is related to other factors than lamp efficacy improvement.

Finally it should be noted that while these improvments were calculated according to the state of art defined in EN 13201-5:2016 and prEN 15193-1:2016 that also so-called BNAT lighting design techniques and systems were identified that go beyond these. Hence, in future even lower LENI and AECI values can be expected compared to what has been calculated in this task.

[197] LENI non LED x 90[lm/W]/136[lm/W] = LENI LED

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 was introduced in Task 1 in Figures 1-1, 1-2 and 1-3. To follow the discussion in the rest of this task report it is important to understand this decomposition and all its defined parameters. It is equally important to be aware that the proposed scope of Task 1 was to focus on installed lighting systems that respect the minimum requirements specified in 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'. In consequence, initial installations are over-dimensioned compared to the minimum required and the maintenance factors as defined in Task 1 are taken into account based on current user practices and maintenance schemes that are explained in the Task 3 report 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 systematically discuss all these potential lighting design improvement options. Moreover, for the purposes of fair comparison it is also important to do this on an equal comparative basis. Therefore in the subsequent sections the improvement design options will be grouped into categories for the set of selected reference lighting applications in Task 3 and analysed at subsystem level as previously defined in Task 1. To do this data was processed in a spreadsheet with the formulas and data of prEN 15193:2016 or EN 13201-5:2016 complementary to this report and the results are included in this task.

For these reference lighting systems we look at the 'current sales or Base Case (BC)' design or a mainstream design and several BAT and BNAT designs options on energy use or other environmental improvements. The indoor and outdoor lighting cases will be discussed in separate sections because of the strong differences in standards and user requirements. Note: in all designs the light source efficacy is clearly included which might be useful for modelling the policy scenarions in Task 7, and to differentiate from the policy scenarios of the lot 7 light source study[198].

In the Best Available Technology(BAT) sections, several options at the installation level are considered seperately from each other and discussed in detail because they were not the subject of the eco-design light source study[198]. For light sources and control gear the BAT from this study[198] will be assumed without repeating the details and their background.

In a final concluding section all data is grouped and compared on energy use.

4.1.1 Indoor lighting base case and BAT reference designs

Approach:
In this task the current sales base case (BC) is compared with different BAT design options for each of the reference applications that were previously defined in Task 3. Note that for each reference application an extensive set of lighting requirements are defined in line with EN 12464-1. Some of these requirements made it difficult and

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

challenging for the lighting designers to obtain a compliant design and are not mainstream installed system performances, for example glare and uniformity requirements. All indoor designs were done in lighting design software Dialux 4.12[199].

First VITO provided base case designs for the reference applications in Dialux without a refined lighting design approach based on information provided on mainstream products and layout practices. These designs did not use LED products, mainly to ensure the poorer optical solutions provided by today's LFL lamps were modelled. However these designs can also be converted to use LEDs in accordance with assumptions regarding LED retrofit solutions based on the available design data. For futher modelling in Task 7 this approach can therefore be considered without any difficulty and therefore such design options are not discussed further in this Chapter.

Following this, optimised designs were supplied in Dialux sofware by experienced lighting designers from seven different lighting manufacturers[200] to seek the best possible design and luminaire fit for the reference applications.

Finally, the calculated outcomes for indoor lighting are expressed in terms of the Lighting Energy Numerical Indicator (LENI)[kWh/(y.m²)] as defined in prEN 15193:2016 and therefore VITO elaborated a spreadsheet from which the results are reported in this section. This spreadsheet behind these calculations also allowed simulation of the impact of adding lighting control systems in line with those functions defined in prEN 15193:201, see Chapter 3.

For all the designs detailed subsystem/component parameters were collected in line with the system definitions in Figure 1-2 and
Figure 1-3 of Task 1. This data provides insight with respect to where the system design improvement potential is obtained and allows calculation of the Task 7 improvement policy scenarios that are independent of the efficacy improvement of the light source itself. Also relevant cost data was collected per design option to permit calculation of the Life Cycle Cost in the event that Tasks 5 and 6 would be completed (this is not the case in this version of the report). Cost data for luminaires were collected from online catalogues. The extra cost for lighting design and controls is sourced from Task 2 and is a markup cost where applicable. From the results it is also clear that the high improvement potentials identified are not only due to an increase of the light source efficacy but also due to improvements in several other factors. Note that the improvement due to increased lamp efficacy on LENI is simple proportional to the efficacy improvement, e.g. in a cellular office LENI could be reduced simply from 19 kWh/(y.m²) with lamp efficacy of 90 lm/w to 12.6 kWh/(y.m²) with LED[201] efficacy of 136 lm/W only. Taking this LED efficacy effect into account one can look at the obtained LENI results for improvement options go much beyond this. Thus it is apparent that the overall lighting system improvement potentials which have been identified are attributable to a combination of many design options and parameters.

In this task design options are grouped into categories wherein the Best Available Technology (BAT) is the best combination of technologies and design practice . These 'groups' of design options are considered for each of the reference applications from Task 3. Due to the many parameters involved obviously many subgroups of design options could have been defined. The data for such analysis is available in principle in the design tables but is left out of the discussion of the results to obtain a

[199] https://www.dial.de/en/dialux/download/
[200] Members of http://www.lightingeurope.org/
[201] LENI non LED x 90[lm/W]/136[lm/W] = LENI LED

comprehensive analysis and set of conclusions. Therefore the following groups of design options are considered for indoor reference applications:

- ‘BC’ means the current sales base case, which is a low cost simple design which still satisfies the minimum requirements of EN 12464-1. These designs were created with non-LED products but could of course also be done with comparable LED products, such as retrofit LED tubes. BC could therefore also be considered as a ‘basic LED’ design, when taking the LED efficacy improvement potential into account as identified in the light source study. Note that these designs already satisfy the EN 12464-1 requirements hence much worse systems may be installed in practice. Thus they are not necessarily the worst case designs found on the market but were created by lighting designers based on simple rules of thumb common to the sector.
- ‘BATLED’ means the best fit with luminaire optics and layout. It uses LED luminaires for which the optics and layout are carefully selected to yield the best results but without yet the full benefits of smart controls.
- ‘BATsmart’ is the BATLED case combined with the most advanced lighting controls defined in EN 15193.
- ‘BATbright’ is the BATsmart case combined with increased surface reflections for the reference designs where this is considered to be possible.
- ‘BATday’ is the BATsmart case with the addition of roof lights that increase the daylight contribution for reference designs where this is considered possible.

Results:
The results of this lighting design exercise and data collection process are summarised in the following tables and are discussed and analysed in the subsequent section.

Table 4-1 Cellular office ceiling mounted application design calculation data

Reference design	BC Taskarea	BC Surrounding	BC Total	BATLED Taskarea	BATLED Surrounding	BATLED Total
Ref geometry & daylight						
Area code	Task	Surrounding		Task	Surrounding	
Reflectance ceiling	0,7	0,7		0,7	0,7	
Reflectance Walls	0,5	0,5		0,5	0,5	
Reflectance floor cavity	0,2	0,2		0,2	0,2	
total number of luminaires in area(Nlum)	2	2		2	2	
Classification of daylight availability in area	Medium	Medium		Medium	Medium	
Pls (power of lamps in luminaire)	56,00	56,00		25,00	25,00	
control gear failure rate per 1000h@70°C(%)	0,20	0,20		0,20	0,20	
ηp = fB (power efficiency of luminaire)	0,89	0,89		1,00	1,00	
Pi (maximum luminaire power)	62,92	62,92		25,00	25,00	
Pn (maximum luminaire power installation total)	125,84	125,84	251,69	50,00	50,00	100,00
Ppc (control power total) (W/m²)			0,00			0,00
ηls (lm/W) =ηL (25°C standard conditions)	90,00	90,00		136,00	136,00	
luminous flux of lamps in luminaire	5040,00	5040,00	20160	3400,00	3400,00	13600
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90		0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90	0,90		0,995	0,995	
CIE flux code N5(RLO) (Luminaire light output ratio)	0,71	0,71	0,71	1,00	1,00	1,00
ηluminaire (lm/W)	56,87	56,87		136,00	136,00	
FLM (Luminaire Maintenance Factor)	0,91	0,91		0,91	0,91	
constant illumination control(EN 15193)	n	n		n	n	
occupancy control type(EN 15193)	Man. On/Off	Man. On/Off		Man. On/Off	Man. On/Off	
room type absence (EN 15193)	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		I: Manual	I: Manual	
type of blinds control (annex F 3.2.4) (EN 15193)	MO	MO		MO	MO	
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,81	0,81	0,81	0,81	0,81	0,81
U (utilance) = ηR			0,90			0,94
overlighting correction on Fcl (dimming scene)	1,00	1,00		1,00	1,00	
Fc (constant illumination factor)	1,00	1,00		1,00	1,00	
Fo (formula E.1) (occupancy)	0,90	0,90		0,90	0,90	
Fd (formula 9) (daylight)	0,61	0,61		0,64	0,61	
no standby control losses when unoccupied			y			y
LENI [kWh/(m²y)] (f 15) (for controls)			0,00			0,00
LENI [kWh/(m²y)] (f 15)	33,9	13,2	19,0	13,8	5,3	7,7
ηinst-u [lm/W] (1/specific load)			41,6			104,0
LPD [W/(100 lx.m²)]			2,4			1,0
Light source cost per luminaire for repair(= lamp or LED lum.)	20,00	20,00		200,00	200,00	
control gear cost per luminaire for repair	40,00	40,00		40,00	40,00	
Luminaire unit cost including lamp and control gear	100,00	100,00		200,00	200,00	
Extra design mark up (€/m²)	0,00	0,00		4,00	4,00	

Reference design	BATsmart Taskarea	BATsmart Surrounding	BATsmart Total	BATbright Taskarea	BATbright Surrounding	BATbright Total
Ref geometry & daylight						
Area code	Task	Surrounding		Task	Surrounding	
Reflectance ceiling	0,7	0,7		0,84	0,84	
Reflectance Walls	0,5	0,5		0,71	0,71	
Reflectance floor cavity	0,2	0,2		0,59	0,59	
total number of luminaires in area(Nlum)	2	2		2	2	
Classification of daylight availability in area	Medium	Medium		Strong	Strong	
Pls (power of lamps in luminaire)	25,00	25,00		25,00	25,00	
control gear failure rate per 1000h@70°C(%)	0,20	0,20		0,20	0,20	
ηp = fB (power efficiency of luminaire)	1,00	1,00		1,00	1,00	
Pi (maximum luminaire power)	25,00	25,00		25,00	25,00	
Pn (maximum luminaire power installation total)	50,00	50,00	100,00	50,00	50,00	100,00
Ppc (control power total) (W/m²)			0,10			0,10
ηls (lm/W) =ηL (25°C standard conditions)	136,00	136,00		136,00	136,00	
luminous flux of lamps in luminaire	3400,00	3400,00	13600	3400,00	3400,00	13600
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90		0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,995	0,995		0,995	0,995	
CIE flux code N5(RLO) (Luminaire light output ratio)	1,00	1,00	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	136,00	136,00		136,00	136,00	
FLM (Luminaire Maintenance Factor)	0,91	0,91		0,91	0,91	
constant illumination control(EN 15193)	y	y		y	y	
occupancy control type(EN 15193)	Auto On/Off	Auto On/Off		Auto On/Off	Auto On/Off	
room type absence (EN 15193)	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)	VIII: =VI but no	VIII: =VI but no auto on		VIII: =VI but no	VIII: =VI but no auto on	
type of blinds control (annex F 3.2.4) (EN 15193)	Auto	Auto		Auto	Auto	
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,81	0,81	0,81	0,81	0,81	0,81
U (utilance) = ηR			0,94			1,27
overlighting correction on Fcl (dimming scene)	1,00	0,70		0,70	0,50	
Fc (constant illumination factor)	0,91	0,64		0,64	0,45	
Fo (formula E.1) (occupancy)	0,80	0,80		0,80	0,80	
Fd (formula 9) (daylight)	0,36	0,37		0,27	0,27	
no standby control losses when unoccupied			y			y
LENI [kWh/(m²y)] (f 15) (for controls)			0,25			0,25
LENI [kWh/(m²y)] (f 15)	7,1	2,0	3,7	4,0	1,1	2,2
ηinst-u [lm/W] (1/specific load)			104,0			140,2
LPD [W/(100 lx.m²)]			1,0			0,7
Light source cost per luminaire for repair(= lamp or LED lum.)	250,00	250,00		250,00	250,00	
control gear cost per luminaire for repair	40,00	40,00		40,00	40,00	
Luminaire unit cost including lamp and control gear	250,00	250,00		250,00	250,00	
Extra design mark up (€/m²)	4,00	4,00		4,00	4,00	

Table 4-2 Cellular office suspended application design calculation data

Reference design	BC Taskarea	BC Surrounding	BC Total	BATLED Taskarea	BATLED Surrounding	BATLED Total
Ref geometry & daylight						
Area code	Task	Surrounding		Task	Surrounding	
Reflectance ceiling	0,7	0,7		0,7	0,7	
Reflectance Walls	0,5	0,5		0,5	0,5	
Reflectance floor cavity	0,2	0,2		0,2	0,2	
total number of luminaires in area(Nlum)	2	2		2	2	
Classification of daylight availability in area	Medium	Medium		Medium	Medium	
Pls (power of lamps in luminaire)	56,00	56,00		36,00	36,00	
control gear failure rate per 1000h@70°C(%)	0,20	0,20		0,20	0,20	
ηp = fB (power efficiency of luminaire)	0,90	0,90		1,00	1,00	
Pi (maximum luminaire power)	62,22	62,22		36,00	36,00	
Pn (maximum luminaire power installation total)	124,44	124,44	248,89	72,00	72,00	144,00
Ppc (control power total) (W/m²)			0,00			0,00
ηls (lm/W) =ηL (25°C standard condictions)	93,75	93,75		113,89	113,89	
luminous flux of lamps in luminaire	5250,00	5250,00	21000	4100,00	4100,00	16400
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90		0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90	0,90		0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	0,89	0,89	0,89	1,00	1,00	1,00
ηluminaire (lm/W)	75,09	75,09		113,89	113,89	
FLM (Luminaire Maintenance Factor)	0,91	0,91		0,91	0,91	
constant illumination control(EN 15193)	n	n		n	n	
occupancy control type(EN 15193)	Man. On/Off	Man. On/Off		Man. On/Off	Man. On/Off	
room type absence (EN 15193)	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		I: Manual	I: Manual	
type of blinds control (annex F 3.2.4) (EN 15193)	MO	MO		MO	MO	
calculated energy performance parameters EN15193 & study defined						
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,81	0,81	0,81	0,81	0,81	0,81
U (utilance) = ηR			0,82			0,86
overlighting correction on Fcl (dimming scene)	1,00	1,00		1,00	1,00	
Fc (constant illumination factor)	1,00	1,00		1,00	1,00	
Fo (formula E.1) (occupancy)	0,90	0,90		0,90	0,90	
Fd (formula 9) (daylight)	0,64	0,61		0,64	0,61	
no standby control losses when unoccupied			y			y
LENI [kWh/(m²y)] (f 15) (for controls)			0,00			0,00
LENI [kWh/(m²y)] (f 15)	34,5	13,1	19,1	19,9	7,6	11,0
ηinst-u [lm/W] (1/specific load)			49,9			79,2
LPD [W/(100 lx.m²)]			2,0			1,3
Light source cost per luminaire for repair(= lamp or LED lum.)	20,00	20,00		350,00	350,00	
control gear cost per luminaire for repair	40,00	40,00		40,00	40,00	
Luminaire unit cost including lamp and control gear	200,00	200,00		350,00	350,00	
Extra design mark up (€/m²)	0,00	0,00		4,00	4,00	

Reference design	BATsmart Taskarea	BATsmart Surrounding	BATsmart Total	BATbright Taskarea	BATbright Surrounding	BATbright Total
Ref geometry & daylight						
Area code	Task	Surrounding		Task	Surrounding	
Reflectance ceiling	0,7	0,7		0,84	0,84	
Reflectance Walls	0,5	0,5		0,71	0,71	
Reflectance floor cavity	0,2	0,2		0,59	0,59	
total number of luminaires in area(Nlum)	2	2		2	2	
Classification of daylight availability in area	Medium	Medium		Strong	Strong	
Pls (power of lamps in luminaire)	36,00	36,00		36,00	36,00	
control gear failure rate per 1000h@70°C(%)	0,20	0,20		0,20	0,20	
ηp = fB (power efficiency of luminaire)	1,00	1,00		1,00	1,00	
Pi (maximum luminaire power)	36,00	36,00		36,00	36,00	
Pn (maximum luminaire power installation total)	72,00	72,00	144,00	72,00	72,00	144,00
Ppc (control power total) (W/m^2)			0,10			0,10
ηls (lm/W) =ηL (25°C standard conditions)	113,89	113,89		113,89	113,89	
luminous flux of lamps in luminaire	4100,00	4100,00	16400	4100,00	4100,00	16400
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90		0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,99	0,99		0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	1,00	1,00	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	113,89	113,89		113,89	113,89	
FLM (Luminaire Maintenance Factor)	0,91	0,91		0,91	0,91	
constant illumination control(EN 15193)	y	y		y	y	
occupancy control type(EN 15193)	Auto On/Off	Auto On/Off		Auto On/Off	Auto On/Off	
room type absence (EN 15193)	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)	VIII: =VI but no	VIII: =VI but no auto on		VIII: =VI but no	VIII: =VI but no auto on	
type of blinds control (annex F 3.2.4) (EN 15193)	Auto	Auto		Auto	Auto	
calculated energy performance parameters EN15193 & study defined						
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,81	0,81	0,81	0,81	0,81	0,81
U (utilance) = ηR			0,86			1,19
overlighting correction on Fcl (dimming scene)	1,00	0,70		0,70	0,50	
Fc (constant illumination factor)	0,91	0,64		0,64	0,45	
Fo (formula E.1) (occupancy)	0,80	0,80		0,80	0,80	
Fd (formula 9) (daylight)	0,36	0,37		0,27	0,27	
no standby control losses when unoccupied			y			y
LENI [kWh/(m²y)] (f 15) (for controls)			0,25			0,25
LENI [kWh/(m²y)] (f 15)	10,2	2,8	4,9	5,8	1,6	2,8
ηinst-u [lm/W] (1/specific load)			79,2			110,3
LPD [W/(100 lx.m²)]			1,3			0,9
Light source cost per luminaire for repair(= lamp or LED lum.)	400,00	400,00		400,00	400,00	
control gear cost per luminaire for repair	40,00	40,00		40,00	40,00	
Luminaire unit cost including lamp and control gear	400,00	400,00		400,00	400,00	
Extra design mark up (€/m²)	4,00	4,00		4,00	4,00	

Table 4-3 Open office ceiling mounted application design calculation data

Reference design	BC Desk&meet area	BC Storage area	BC Surrounding	BC Total	BATLED Desk&meet area	BATLED Storage area	BATLED Surrounding	BATLED Total
Ref geometry & daylight								
Area code	desk	storage	Surrounding		desk	storage	Surrounding	
Reflectance ceiling	0,7	0,7	0,7		0,7	0,7	0,7	
Reflectance Walls	0,5	0,5	0,5		0,5	0,5	0,5	
Reflectance floor cavity	0,2	0,2	0,2		0,2	0,2	0,2	
total number of luminaires in area(Nlum)	21	8	6		21	8	6	
Classification of daylight availability in area	Low	Medium	Medium		Low	Medium	Medium	
Pls (power of lamps in luminaire)	56,00	56,00	56,00		25,00	25,00	25,00	
control gear failure rate per 1000h@70°C(%)	0,20	0,20	0,20		0,20	0,20	0,20	
ηp = fB (power efficiency of luminaire)	0,89	0,89	0,89		1,00	1,00	1,00	
Pi (maximum luminaire power)	62,92	62,92	62,92		25,00	25,00	25,00	
Pn (maximum luminaire power installation total)	1321,35	503,37	377,53	2202,25	525,00	200,00	150,00	875,00
Ppc (control power total) (W/m²)				0,00				0,00
ηls (lm/W) =ηL (25°C standard condictions)	89,50	89,50	89,50		136,00	136,00	136,00	
luminous flux of lamps in luminaire	5012,00	5012,00	5012,00	175420,00	3400,00	3400,00	3400,00	119000,00
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90	0,90		0,90	0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90	0,90	0,90		0,99	0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	0,71	0,71	0,71	0,71	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	56,56	56,56	56,56		136,00	136,00	136,00	
FLM (Luminaire Maintenance Factor)	0,91	0,91	0,91		0,91	0,91	0,91	
constant illumination control(EN 15193)	n	n	n		n	n	n	
occupancy control type(EN 15193)	Man. On/Off	Man. On/Off	Man. On/Off		Man. On/Off	Man. On/Off	Man. On/Off	
room type absence (EN 15193)	Open>sense 3	Open>sense 30r	Open>sense 30m²		Open>sense 3	Open>sense 30r	Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	I: Manual	I: Manual	I: Manual		I: Manual	I: Manual	I: Manual	
type of blinds control (annex F 3.2.4) (EN 15193)	MO	MO	MO		MO	MO	MO	
calculated energy performance parameters EN15193 & study defined								
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81
U (utilance) = ηR				1,00				0,99
overlighting correction on Fcl (dimming scene)	1,00	1,00	1,00		1,00	1,00	1,00	
Fc (constant illumination factor)	1,00	1,00	1,00		1,00	1,00	1,00	
Fo (formula E.1) (occupancy)	1,00	1,00	1,00		1,00	1,00	1,00	
Fd (formula 9) (daylight)	0,70	0,61	0,64		0,70	0,61	0,64	
no standby control losses when unoccupied				y				y
LENI [kWh/(m²y)] (f 15) (for controls)				0,00				0,00
LENI [kWh/(m²y)] (f 15)	23,8	29,9	13,9	22,1	9,4	11,9	5,5	8,8
ηinst-u [lm/W] (1/specific load)				45,8				109,2
LPD [W/(100 lx.m²)]				2,2				0,9
Light source cost per luminaire for repair(= lamp or LED lum.)	20,00	20,00	20,00		200,00	200,00	200,00	
control gear cost per luminaire for repair	40,00	40,00	40,00		40,00	40,00	40,00	
Luminaire unit cost including lamp and control gear	100,00	100,00	100,00		200,00	200,00	200,00	
Extra design mark up (€/m²)	0,00	0,00	0,00		4,00	4,00	4,00	

Reference design	BATsmart Desk&meet area	BATsmart Storage area	BATsmart Surrounding	BATsmart Total	BC Desk&meet area	BC Storage area	BC Surrounding	BC Total
Ref geometry & daylight								
Area code	desk	storage	Surrounding		desk	storage	Surrounding	
Reflectance ceiling	0,7	0,7	0,7		0,7	0,7	0,7	
Reflectance Walls	0,5	0,5	0,5		0,5	0,5	0,5	
Reflectance floor cavity	0,2	0,2	0,2		0,2	0,2	0,2	
total number of luminaires in area(Nlum)	21	8	6		21	8	6	
Classification of daylight availability in area	Low	Medium	Medium		Low	Medium	Medium	
Pls (power of lamps in luminaire)	25,00	25,00	25,00		25,00	25,00	25,00	
control gear failure rate per 1000h@70°C(%)	0,20	0,20	0,20		0,20	0,20	0,20	
ηp = fB (power efficiency of luminaire)	1,00	1,00	1,00		1,00	1,00	1,00	
Pi (maximum luminaire power)	25,00	25,00	25,00		25,00	25,00	25,00	
Pn (maximum luminaire power installation total)	525,00	200,00	150,00	875,00	525,00	200,00	150,00	875,00
Ppc (control power total) (W/m²)				0,10				0,10
ηls (lm/W) =ηL (25°C standard condictions)	136,00	136,00	136,00		136,00	136,00	136,00	
luminous flux of lamps in luminaire	3400,00	3400,00	3400,00	119000,00	3400,00	3400,00	3400,00	119000,00
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90	0,90		0,90	0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,99	0,99	0,99		0,99	0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	136,00	136,00	136,00		136,00	136,00	136,00	
FLM (Luminaire Maintenance Factor)	0,91	0,91	0,91		0,91	0,91	0,91	
constant illumination control(EN 15193)	y	y	y		y	y	y	
occupancy control type(EN 15193)	presence det.	presence det.	presence det.		presence det.	presence det.	presence det.	
room type absence (EN 15193)	Open>sense 3	Open>sense 30r	Open>sense 30m²		Open>sense 3	Open>sense 30r	Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	V: Dim&noSB	V: Dim&noSB	V: Dim&noSB		V: Dim&noSB	V: Dim&noSB	V: Dim&noSB	
type of blinds control (annex F 3.2.4) (EN 15193)	Auto	Auto	Auto		Auto	Auto	Auto	
calculated energy performance parameters EN15193 & study defined								
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81
U (utilance) = ηR				0,99				1,55
overlighting correction on Fcl (dimming scene)	0,95	0,70	0,70		0,65	0,50	0,50	
Fc (constant illumination factor)	0,86	0,64	0,64		0,59	0,45	0,45	
Fo (formula E.1) (occupancy)	1,00	1,00	1,00		1,00	1,00	1,00	
Fd (formula 9) (daylight)	0,54	0,48	0,46		0,54	0,48	0,46	
no standby control losses when unoccupied				y				y
LENI [kWh/(m²y)] (f 15) (for controls)				0,25				0,25
LENI [kWh/(m²y)] (f 15)	6,6	6,2	2,7	5,7	4,5	4,4	1,9	4,1
ηinst-u [lm/W] (1/specific load)				109,2				170,8
LPD [W/(100 lx.m²)]				0,9				0,6
Light source cost per luminaire for repair(= lamp or LED lum.)	250,00	250,00	250,00		250,00	250,00	250,00	
control gear cost per luminaire for repair	40,00	40,00	40,00		40,00	40,00	40,00	
Luminaire unit cost including lamp and control gear	250,00	250,00	250,00		250,00	250,00	250,00	
Extra design mark up (€/m²)	4,00	4,00	4,00		4,00	4,00	4,00	

Table 4-4 Open office suspended application design calculation data

Reference design	BC Desk&meet area	BC Storage area	BC Surrounding	BC Total	BATLED Desk&meet area	BATLED Storage area	BATLED Surrounding	BATLED Total
Ref geometry & daylight								
Area code	desk	storage	Surrounding		desk	storage	Surrounding	
Reflectance ceiling	0,7	0,7	0,7		0,7	0,7	0,7	
Reflectance Walls	0,5	0,5	0,5		0,5	0,5	0,5	
Reflectance floor cavity	0,2	0,2	0,2		0,2	0,2	0,2	
total number of luminaires in area(Nlum)	20	6	2		20	6	2	
Classification of daylight availability in area	Low	Medium	Medium		Low	Medium	Medium	
Pls (power of lamps in luminaire)	56,00	56,00	56,00		36,00	36,00	36,00	
control gear failure rate per 1000h@70°C(%)	0,20	0,20	0,20		0,20	0,20	0,20	
ηp = fB (power efficiency of luminaire)	0,90	0,90	0,90		1,00	1,00	1,00	
Pi (maximum luminaire power)	62,22	62,22	62,22		36,00	36,00	36,00	
Pn (maximum luminaire power installation total)	1244,44	373,33	124,44	1742,22	720,00	216,00	72,00	1008,00
Ppc (control power total) (W/m²)				0,00				0,00
ηls (lm/W) =ηL (25°C standard conditions)	93,75	93,75	93,75		113,89	113,89	113,89	
luminous flux of lamps in luminaire	5250,00	5250,00	5250,00	147000,00	4100,00	4100,00	4100,00	114800,00
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90	0,90		0,90	0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90	0,90	0,90		0,99	0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	0,89	0,89	0,89	0,89	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	75,09	75,09	75,09		113,89	113,89	113,89	
FLM (Luminaire Maintenance Factor)	0,91	0,91	0,91		0,91	0,91	0,91	
constant illumination control(EN 15193)	n	n	n		n	n	n	
occupancy control type(EN 15193)	Man. On/Off	Man. On/Off	Man. On/Off		Man. On/Off	Man. On/Off	Man. On/Off	
room type absence (EN 15193)	Open>sense 3	Open>sense 30r	Open>sense 30m²		Open>sense 3	Open>sense 30r	Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	I: Manual	I: Manual	I: Manual		I: Manual	I: Manual	I: Manual	
type of blinds control (annex F 3.2.4) (EN 15193)	MO	MO	MO		MO	MO	MO	
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81
U (utilance) = ηR				0,94				0,98
overlighting correction on Fcl (dimming scene)	1,00	1,00	1,00		1,00	1,00	1,00	
Fc (constant illumination factor)	1,00	1,00	1,00		1,00	1,00	1,00	
Fo (formula E.1) (occupancy)	1,00	1,00	1,00		1,00	1,00	1,00	
Fd (formula 9) (daylight)	0,70	0,61	0,64		0,70	0,61	0,64	
no standby control losses when unoccupied				y				y
LENI [kWh/(m²y)] (f 15) (for controls)				0,00				0,00
LENI [kWh/(m²y)] (f 15)	22,4	22,1	4,6	17,7	12,9	12,8	2,6	10,2
ηinst-u [lm/W] (1/specific load)				57,4				90,8
LPD [W/(100 lx.m²)]				1,7				1,1
Light source cost per luminaire for repair(= lamp or LED lum.)	20,00	20,00	20,00		350,00	350,00	350,00	
control gear cost per luminaire for repair	40,00	40,00	40,00		40,00	40,00	40,00	
Luminaire unit cost including lamp and control gear	200,00	200,00	200,00		350,00	350,00	350,00	
Extra design mark up (€/m²)	0,00	0,00	0,00		4,00	4,00	4,00	

Reference design	BATsmart Desk&meet area	BATsmart Storage area	BATsmart Surrounding	BATsmart Total	BC Desk&meet area	BC Storage area	BC Surrounding	BC Total
Ref geometry & daylight								
Area code	desk	storage	Surrounding		desk	storage	Surrounding	
Reflectance ceiling	0,7	0,7	0,7		0,7	0,7	0,7	
Reflectance Walls	0,5	0,5	0,5		0,5	0,5	0,5	
Reflectance floor cavity	0,2	0,2	0,2		0,2	0,2	0,2	
total number of luminaires in area(Nlum)	20	6	2		20	6	2	
Classification of daylight availability in area	Low	Medium	Medium		Low	Medium	Medium	
Pls (power of lamps in luminaire)	36,00	36,00	36,00		36,00	36,00	36,00	
control gear failure rate per 1000h@70°C(%)	0,20	0,20	0,20		0,20	0,20	0,20	
ηp = fB (power efficiency of luminaire)	1,00	1,00	1,00		1,00	1,00	1,00	
Pi (maximum luminaire power)	36,00	36,00	36,00		36,00	36,00	36,00	
Pn (maximum luminaire power installation total)	720,00	216,00	72,00	1008,00	720,00	216,00	72,00	1008,00
Ppc (control power total) (W/m²)				0,10				0,10
ηls (lm/W) =ηL (25°C standard conditions)	113,89	113,89	113,89		113,89	113,89	113,89	
luminous flux of lamps in luminaire	4100,00	4100,00	4100,00	114800,00	4100,00	4100,00	4100,00	114800,00
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90	0,90		0,90	0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,99	0,99	0,99		0,99	0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	113,89	113,89	113,89		113,89	113,89	113,89	
FLM (Luminaire Maintenance Factor)	0,91	0,91	0,91		0,91	0,91	0,91	
constant illumination control(EN 15193)	y	y	y		y	y	y	
occupancy control type(EN 15193)	presence det.	presence det.	presence det.		presence det.	presence det.	presence det.	
room type absence (EN 15193)	Open>sense 3	Open>sense 30r	Open>sense 30m²		Open>sense 3	Open>sense 30r	Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	V: Dim&noSB	V: Dim&noSB	V: Dim&noSB		V: Dim&noSB	V: Dim&noSB	V: Dim&noSB	
type of blinds control (annex F 3.2.4) (EN 15193)	Auto	Auto	Auto		Auto	Auto	Auto	
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,81	0,81	0,81	0,81	0,81	0,81	0,81	0,81
U (utilance) = ηR				0,98				1,55
overlighting correction on Fcl (dimming scene)	0,95	0,70	0,70		0,65	0,50	0,50	
Fc (constant illumination factor)	0,86	0,64	0,64		0,59	0,45	0,45	
Fo (formula E.1) (occupancy)	1,00	1,00	1,00		1,00	1,00	1,00	
Fd (formula 9) (daylight)	0,54	0,48	0,46		0,54	0,48	0,46	
no standby control losses when unoccupied				y				y
LENI [kWh/(m²y)] (f 15) (for controls)				0,25				0,25
LENI [kWh/(m²y)] (f 15)	9,0	6,7	1,3	6,9	6,2	4,8	0,9	4,8
ηinst-u [lm/W] (1/specific load)				90,8				143,2
LPD [W/(100 lx.m²)]				1,1				0,7
Light source cost per luminaire for repair(= lamp or LED lum.)	400,00	400,00	400,00		400,00	400,00	400,00	
control gear cost per luminaire for repair	40,00	40,00	40,00		40,00	40,00	40,00	
Luminaire unit cost including lamp and control gear	400,00	400,00	400,00		400,00	400,00	400,00	
Extra design mark up (€/m²)	4,00	4,00	4,00		4,00	4,00	4,00	

Table 4-5 Corridor application data

Reference design	BC Taskarea	BC Total	BATLED Taskarea	BATLED Total	BATsmart Taskarea	BATsmart Total	BATbright Taskarea	BATbright Total
Ref geometry & daylight								
Area code	floor		floor		floor		floor	
Reflectance ceiling	0,7		0,7		0,7		0,84	
Reflectance Walls	0,5		0,5		0,5		0,71	
Reflectance floor cavity	0,2		0,2		0,2		0,59	
total number of luminaires in area(Nlum)	6		6		6		6	
Classification of daylight availability in area	None		None		None		None	
Pls (power of lamps in luminaire)	26,00		10,00		10,00		10,00	
control gear failure rate per 1000h@70°C(%)	0,20		0,20		0,20		0,20	
ηp = fB (power efficiency of luminaire)	1,00		1,00		1,00		1,00	
Pi (maximum luminaire power)	26,00		10,00		10,00		10,00	
Pn (maximum luminaire power installation total)	156,00	156,00	60,00	60,00	60,00	60,00	60,00	60,00
Ppc (control power total) (W/m²)		0,00		0,00		0,10		0,10
ηls (lm/W) =ηL (25°C standard conditions)	69,23		120,00		120,00		120,00	
luminous flux of lamps in luminaire	1800,00	10800	1200,00	7200	1200,00	7200	1200,00	7200
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90		0,90		0,90		0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90		0,99		0,99		0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	0,61	0,61	0,89	0,89	0,89	0,89	0,89	0,89
ηluminaire (lm/W)	42,23		106,80		106,80		106,80	
FLM (Luminaire Maintenance Factor)	0,91		0,91		0,91		0,91	
constant illumination control(EN 15193)	n		n		y		y	
occupancy control type(EN 15193)	Man.+sweepoff		Man.+sweepoff		Auto On/Off		Auto On/Off	
room type absence (EN 15193)	Corridor (dimmed)		Corridor (dimmed)		Corridor (dimmed)		Corridor (dimmed)	
type of daylight control (Table F.16) (EN 15193)	I: Manual		I: Manual		I: Manual		I: Manual	
type of blinds control (annex F 3.2.4) (EN 15193)	None		None		None		None	
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,79	0,79	0,79	0,79	0,79	0,79	0,79	0,79
U (utilance) = ηR		0,50		0,53		0,53		0,80
overlighting correction on Fcl (dimming scene)	1,00		1,00		1,00		0,70	
Fc (constant illumination factor)	1,00		1,00		0,91		0,64	
Fo (formula E.1) (occupancy)	0,75		0,75		0,70		0,70	
Fd (formula 9) (daylight)	1,00		1,00		1,00		1,00	
no standby control losses when unoccupied		y		y		y		y
LENI [kWh/(m²y)] (f 15) (for controls)		0,00		0,00		0,25		0,25
LENI [kWh/(m²y)] (f 15)	11,3	11,3	4,3	4,3	3,7	3,9	2,6	2,8
ηinst-u [lm/W] (1/specific load)		16,8		45,4		45,4		68,3
LPD [W/(100 lx.m²)]		6,0		2,2		2,2		1,5
Light source cost per luminaire for repair(= lamp or LED lum.)	5,00		75,00		100,00		100,00	
control gear cost per luminaire for repair	20,00		25,00		25,00		25,00	
Luminaire unit cost including lamp and control gear	50,00		75,00		100,00		100,00	
Extra design mark up (€/m²)	0,00		4,00		4,00		4,00	

Table 4-6 Large DIY application design calculation data

Reference design	BC sales	BC cashier	BC Entrance	BC Total	BCday sales	BCday cashier	BCday Entrance	BCday Total
Ref geometry & daylight								
Area code	sales	cashier	entrance		sales	cashier	entrance	
Reflectance ceiling	0,7	0,7	0,7		0,7	0,7	0,7	
Reflectance Walls	0,5	0,5	0,5		0,5	0,5	0,5	
Reflectance floor cavity	0,2	0,2	0,2		0,2	0,2	0,2	
total number of luminaires in area(Nlum)	704	30	87		704	30	87	
Classification of daylight availability in area	None	Medium	Strong		Strong	Strong	Strong	
Pls (power of lamps in luminaire)	108,00	108,00	108,00		108,00	108,00	108,00	
control gear failure rate per 1000h@70°C(%)	0,20	0,20	0,20		0,20	0,20	0,20	
ηp = fB (power efficiency of luminaire)	0,91	0,91	0,91		0,91	0,91	0,91	
Pi (maximum luminaire power)	118,68	118,68	118,68		118,68	118,68	118,68	
Pn (maximum luminaire power installation total)	83551,65	3560,44	10325,27	97437,36	83551,65	3560,44	10325,27	97437,36
Ppc (control power total) (W/m²)				0,00				0,00
ηls (lm/W) =ηL (25°C standard conditions)	82,41	82,41	82,41		82,41	82,41	82,41	
luminous flux of lamps in luminaire	8900,00	8900,00	8900,00	7306900,00	8900,00	8900,00	8900,00	7306900,00
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90	0,90		0,90	0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90	0,90	0,90		0,99	0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	0,95	0,95	0,95	0,95	0,95	0,95	0,95	0,95
ηluminaire (lm/W)	71,24	71,24	71,24		71,24	71,24	71,24	
FLM (Luminaire Maintenance Factor)	0,92	0,92	0,92		0,92	0,92	0,92	
constant illumination control(EN 15193)	n	n	n		n	n	n	
occupancy control type(EN 15193)	Man. On/Off	Man. On/Off	Man. On/Off		Man. On/Off	Man. On/Off	Man. On/Off	
room type absence (EN 15193)	Open>sense 3	Open>sense 30r	Open>sense 30m²		Open>sense 3	Open>sense 30r	Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	I: Manual	I: Manual	I: Manual		I: Manual	I: Manual	I: Manual	
type of blinds control (annex F 3.2.4) (EN 15193)	MO	MO	MO		MO	MO	MO	
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,82	0,82	0,82	0,82	0,82	0,82	0,82	0,82
U (utilance) = ηR				1,12				1,12
overlighting correction on Fcl (dimming scene)	1,00	1,00	1,00		1,00	1,00	1,00	
Fc (constant illumination factor)	1,00	1,00	1,00		1,00	1,00	1,00	
Fo (formula E.1) (occupancy)	1,00	1,00	1,00		1,00	1,00	1,00	
Fd (formula 9) (daylight)	1,00	0,64	0,56		0,56	0,56	0,56	
no standby control losses when unoccupied				y				y
LENI [kWh/(m²y)] (f 15) (for controls)				0,00				0,00
LENI [kWh/(m²y)] (f 15)	46,3	40,7	57,7	46,9	33,6	38,2	57,7	35,3
ηinst-u [lm/W] (1/specific load)				65,4				65,4
LPD [W/(100 lx.m²)]				1,5				1,5
Light source cost per luminaire for repair(= lamp or LED lum.)	20,00	20,00	20,00		20,00	20,00	20,00	
control gear cost per luminaire for repair	40,00	40,00	40,00		40,00	40,00	40,00	
Luminaire unit cost including lamp and control gear	150,00	150,00	150,00		150,00	150,00	150,00	
Extra design mark up (€/m²)	0,00	0,00	0,00		4,00	4,00	4,00	

Reference design	BATLED sales	BATLED cashier	BATLED Entrance	BATLED Total	BATsmart sales	BATsmart cashier	BATsmart Entrance	BATsmart Total
Ref geometry & daylight								
Area code	sales	cashier	entrance		sales	cashier	entrance	
Reflectance ceiling	0,7	0,7	0,7		0,7	0,7	0,7	
Reflectance Walls	0,5	0,5	0,5		0,5	0,5	0,5	
Reflectance floor cavity	0,2	0,2	0,2		0,2	0,2	0,2	
total number of luminaires in area(Nlum)	608	30	87		608	30	87	
Classification of daylight availability in area	None	Medium	Strong		None	Medium	Strong	
Pls (power of lamps in luminaire)	75,30	50,40	50,40		75,30	50,40	50,40	
control gear failure rate per 1000h@70°C(%)	0,20	0,20	0,20		0,20	0,20	0,20	
ηp = fB (power efficiency of luminaire)	1,00	1,00	1,00		1,00	1,00	1,00	
Pi (maximum luminaire power)	75,30	50,40	50,40		75,30	50,40	50,40	
Pn (maximum luminaire power installation total)	45782,40	1512,00	4384,80	51679,20	45782,40	1512,00	4384,80	51679,20
Ppc (control power total) (W/m²)				0,00				0,10
ηls (lm/W) =ηL (25°C standard conditions)	137,20	145,90	145,90		137,20	145,90	145,90	
luminous flux of lamps in luminaire	10331,16	7353,36	7353,36	7141688,40	10331,16	7353,36	7353,36	7141688,40
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90	0,90		0,90	0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,99	0,99	0,99		0,99	0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	137,20	145,90	145,90		137,20	145,90	145,90	
FLM (Luminaire Maintenance Factor)	0,92	0,92	0,92		0,92	0,92	0,92	
constant illumination control(EN 15193)	n	n	n		y	y	y	
occupancy control type(EN 15193)	Man. On/Off	Man. On/Off	Man. On/Off		Man. On/Off	Man. On/Off	Man. On/Off	
room type absence (EN 15193)	Open>sense 3	Open>sense 30r	Open>sense 30m²		Open>sense 3	Open>sense 30r	Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	I: Manual	I: Manual	I: Manual		I: Manual	V: Dim&noSB	V: Dim&noSB	
type of blinds control (annex F 3.2.4) (EN 15193)	MO	MO	MO		MO	MO	MO	
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,82	0,82	0,82	0,82	0,82	0,82	0,82	0,82
U (utilance) = ηR				1,11				1,11
overlighting correction on Fcl (dimming scene)	1,00	1,00	1,00		1,00	0,95	0,70	
Fc (constant illumination factor)	1,00	1,00	1,00		0,91	0,87	0,64	
Fo (formula E.1) (occupancy)	1,00	1,00	1,00		1,00	1,00	1,00	
Fd (formula 9) (daylight)	1,00	0,64	0,56		1,00	0,49	0,42	
no standby control losses when unoccupied				y				y
LENI [kWh/(m²y)] (f 15) (for controls)				0,00				0,40
LENI [kWh/(m²y)] (f 15)	25,4	17,3	24,5	25,1	23,2	13,2	13,8	22,7
ηinst-u [lm/W] (1/specific load)				125,7				125,7
LPD [W/(100 lx.m²)]				0,8				0,8
Light source cost per luminaire for repair(= lamp or LED lum.)	300,00	250,00	250,00		300,00	300,00	300,00	
control gear cost per luminaire for repair	50,00	50,00	50,00		50,00	50,00	50,00	
Luminaire unit cost including lamp and control gear	300,00	250,00	250,00		300,00	300,00	300,00	
Extra design mark up (€/m²)	4,00	4,00	4,00		4,00	4,00	4,00	

Reference design	BATday sales	BATday cashier	BATday Entrance	BATday Total	BATbrightday sales	BATbright day cashier	BATbrightday Entrance	BATbright day Total
Ref geometry & daylight								
Area code	sales	cashier	entrance		sales	cashier	entrance	
Reflectance ceiling	0,7	0,7	0,7		0,84	0,84	0,84	
Reflectance Walls	0,5	0,5	0,5		0,5	0,5	0,5	
Reflectance floor cavity	0,2	0,2	0,2		0,2	0,2	0,2	
total number of luminaires in area(Nlum)	608	30	87		608	30	87	
Classification of daylight availability in area	Strong	Strong	Strong		Strong	Strong	Strong	
Pls (power of lamps in luminaire)	75,30	50,40	50,40		75,30	50,40	50,40	
control gear failure rate per 1000h@70°C(%)	0,20	0,20	0,20		0,20	0,20	0,20	
ηp = fB (power efficiency of luminaire)	1,00	1,00	1,00		1,00	1,00	1,00	
Pi (maximum luminaire power)	75,30	50,40	50,40		75,30	50,40	50,40	
Pn (maximum luminaire power installation total)	45782,40	1512,00	4384,80	51679,20	45782,40	1512,00	4384,80	51679,20
Ppc (control power total) (W/m²)				0,10				0,10
ηls (lm/W) =ηL (25°C standard conditions)	137,20	145,90	145,90		137,20	145,90	145,90	
luminous flux of lamps in luminaire	10331,16	7353,36	7353,36	7141688,40	10331,16	7353,36	7353,36	7141688,40
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90	0,90		0,90	0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,99	0,99	0,99		0,99	0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	137,20	145,90	145,90		137,20	145,90	145,90	
FLM (Luminaire Maintenance Factor)	0,92	0,92	0,92		0,92	0,92	0,92	
constant illumination control(EN 15193)	y	y	y		y	y	y	
occupancy control type(EN 15193)	Man. On/Off	Man. On/Off	Man. On/Off		Man. On/Off	Man. On/Off	Man. On/Off	
room type absence (EN 15193)	Open>sense 3	Open>sense 30r	Open>sense 30m²		Open>sense 3	Open>sense 30r	Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	VIII: =VI but no	V: Dim&noSB	VII: =V but no auto on		VIII: =VI but no	V: Dim&noSB	VII: =V but no auto on	
type of blinds control (annex F 3.2.4) (EN 15193)	MO	MO	MO		MO	MO	MO	
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,82	0,82	0,82	0,82	0,82	0,82	0,82	0,82
U (utilance) = ηR				1,11				1,14
overlighting correction on Fcl (dimming scene)	1,00	0,95	0,70		0,85	0,90	0,60	
Fc (constant illumination factor)	0,91	0,87	0,64		0,78	0,82	0,55	
Fo (formula E.1) (occupancy)	1,00	1,00	1,00		1,00	1,00	1,00	
Fd (formula 9) (daylight)	0,31	0,42	0,36		0,31	0,42	0,36	
no standby control losses when unoccupied				y				y
LENI [kWh/(m²y)] (f 15) (for controls)				0,40				0,40
LENI [kWh/(m²y)] (f 15)	13,2	12,4	13,0	13,6	11,3	11,7	11,1	11,7
ηinst-u [lm/W] (1/specific load)				125,7				129,3
LPD [W/(100 lx.m²)]				0,8				0,8
Light source cost per luminaire for repair(= lamp or LED lum.)	300,00	300,00	300,00		300,00	300,00	300,00	
control gear cost per luminaire for repair	50,00	50,00	50,00		50,00	50,00	50,00	
Luminaire unit cost including lamp and control gear	300,00	300,00	300,00		300,00	300,00	300,00	
Extra design mark up (€/m²)	4,00	4,00	4,00		4,00	4,00	4,00	

Table 4-7 Supermarket application design calculation data

Reference design	BC sales	BC cashier	BC Entrance	BC Total	BATLED sales	BATLED cashier	BATLED Entrance	BATLED Total
Ref geometry & daylight								
Area code	sales	cashier	entrance		sales	cashier	entrance	
Reflectance ceiling	0,7	0,7	0,7		0,7	0,7	0,7	
Reflectance Walls	0,5	0,5	0,5		0,5	0,5	0,5	
Reflectance floor cavity	0,2	0,2	0,2		0,2	0,2	0,2	
total number of luminaires in area(Nlum)	180	8	16		150	7	14	
Classification of daylight availability in area	None	Medium	Strong		None	Medium	Strong	
Pls (power of lamps in luminaire)	80,00	80,00	80,00		50,40	50,40	50,40	
control gear failure rate per 1000h@70°C(%)	0,20	0,20	0,20		0,20	0,20	0,20	
ηp = fB (power efficiency of luminaire)	0,92	0,92	0,92		1,00	1,00	1,00	
Pi (maximum luminaire power)	86,96	86,96	86,96		50,40	50,40	50,40	
Pn (maximum luminaire power installation total)	15652,17	695,65	1391,30	17739,13	7560,00	352,80	705,60	8618,40
Ppc (control power total) (W/m²)				0,00				0,00
ηls (lm/W) =ηL (25°C standard conditions)	77,00	77,00	77,00		145,60	145,60	145,60	
luminous flux of lamps in luminaire	6160,00	6160,00	6160,00	1256640,00	7338,24	7338,24	7338,24	1254839,04
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90	0,90		0,90	0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90	0,90	0,90		0,99	0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	0,99	0,99	0,99	0,99	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	70,13	70,13	70,13		145,60	145,60	145,60	
FLM (Luminaire Maintenance Factor)	0,92	0,92	0,92		0,92	0,92	0,92	
constant illumination control(EN 15193)	n	n	n		n	n	n	
occupancy control type(EN 15193)	Man. On/Off	Man. On/Off	Man. On/Off		Man. On/Off	Man. On/Off	Man. On/Off	
room type absence (EN 15193)	Open>sense 3	Open>sense 30r	Open>sense 30m²		Open>sense 3	Open>sense 30r	Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	I: Manual	I: Manual	I: Manual		I: Manual	I: Manual	I: Manual	
type of blinds control (annex F 3.2.4) (EN 15193)	MO	MO	MO		MO	MO	MO	
calculated energy performance parameters EN15193 & study defined								
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,82	0,82	0,82	0,82	0,82	0,82	0,82	0,82
U (utilance) = ηR				1,09				1,09
overlighting correction on Fcl (dimming scene)	1,00	1,00	1,00		1,00	1,00	1,00	
Fc (constant illumination factor)	1,00	1,00	1,00		1,00	1,00	1,00	
Fo (formula E.1) (occupancy)	1,00	1,00	1,00		1,00	1,00	1,00	
Fd (formula 9) (daylight)	1,00	0,64	0,56		1,00	0,64	0,56	
no standby control losses when unoccupied				y				y
LENI [kWh/(m²y)] (f 15) (for controls)				0,00				0,00
LENI [kWh/(m²y)] (f 15)	65,6	26,9	24,4	57,3	31,7	13,6	12,4	27,8
ηinst-u [lm/W] (1/specific load)				62,6				129,9
LPD [W/(100 lx.m²)]				1,6				0,8
Light source cost per luminaire for repair(= lamp or LED lum.)	20,00	20,00	20,00		250,00	250,00	250,00	
control gear cost per luminaire for repair	40,00	40,00	40,00		40,00	40,00	40,00	
Luminaire unit cost including lamp and control gear	150,00	150,00	150,00		250,00	250,00	250,00	
Extra design mark up (€/m²)	0,00	0,00	0,00		4,00	4,00	4,00	

Reference design	BATsmart sales	BATsmart cashier	BATsmart Entrance	BATsmart Total	BATday sales	BATday cashier	BATday Entrance	BATday Total
Ref geometry & daylight								
Area code	sales	cashier	entrance		sales	cashier	entrance	
Reflectance ceiling	0,7	0,7	0,7		0,7	0,7	0,7	
Reflectance Walls	0,5	0,5	0,5		0,5	0,5	0,5	
Reflectance floor cavity	0,2	0,2	0,2		0,2	0,2	0,2	
total number of luminaires in area(Nlum)	150	7	14		150	7	14	
Classification of daylight availability in area	None	Medium	Strong		Strong	Strong	Strong	
Pls (power of lamps in luminaire)	50,40	50,40	50,40		50,40	50,40	50,40	
control gear failure rate per 1000h@70°C(%)	0,20	0,20	0,20		0,20	0,20	0,20	
ηp = fB (power efficiency of luminaire)	1,00	1,00	1,00		1,00	1,00	1,00	
Pi (maximum luminaire power)	50,40	50,40	50,40		50,40	50,40	50,40	
Pn (maximum luminaire power installation total)	7560,00	352,80	705,60	8618,40	7560,00	352,80	705,60	8618,40
Ppc (control power total) (W/m²)				0,10				0,10
ηls (lm/W) =ηL (25°C standard conditions)	145,60	145,60	145,60		145,60	145,60	145,60	
luminous flux of lamps in luminaire	7338,24	7338,24	7338,24	1254839,04	7338,24	7338,24	7338,24	1254839,04
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90	0,90	0,90		0,90	0,90	0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,99	0,99	0,99		0,99	0,99	0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	145,60	145,60	145,60		145,60	145,60	145,60	
FLM (Luminaire Maintenance Factor)	0,92	0,92	0,92		0,92	0,92	0,92	
constant illumination control(EN 15193)	y	y	y		y	y	y	
occupancy control type(EN 15193)	Man. On/Off	Man. On/Off	Man. On/Off		Auto On/Dim	Auto On/Dim	Auto On/Dim	
room type absence (EN 15193)	Open>sense 3	Open>sense 30r	Open>sense 30m²		Open>sense 3	Open>sense 30r	Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	I: Manual	VIII: =VI but no a	VIII: =VI but no auto on		I: Manual	VIII: =VI but no a	VIII: =VI but no auto on	
type of blinds control (annex F 3.2.4) (EN 15193)	MO	MO	MO		MO	MO	MO	
calculated energy performance parameters EN15193 & study defined								
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,82	0,82	0,82	0,82	0,82	0,82	0,82	0,82
U (utilance) = ηR				1,09				1,09
overlighting correction on Fcl (dimming scene)	1,00	1,00	0,70		1,00	1,00	0,70	
Fc (constant illumination factor)	0,91	0,91	0,64		0,91	0,91	0,64	
Fo (formula E.1) (occupancy)	1,00	1,00	1,00		1,00	1,00	1,00	
Fd (formula 9) (daylight)	1,00	0,40	0,31		0,56	0,31	0,31	
no standby control losses when unoccupied				y				y
LENI [kWh/(m²y)] (f 15) (for controls)				0,40				0,40
LENI [kWh/(m²y)] (f 15)	28,9	10,0	6,2	25,0	21,0	9,2	6,2	18,6
ηinst-u [lm/W] (1/specific load)				129,9				129,9
LPD [W/(100 lx.m²)]				0,8				0,8
Light source cost per luminaire for repair(= lamp or LED lum.)	250,00	300,00	300,00		250,00	300,00	300,00	
control gear cost per luminaire for repair	40,00	40,00	40,00		40,00	40,00	40,00	
Luminaire unit cost including lamp and control gear	250,00	300,00	300,00		250,00	300,00	300,00	
Extra design mark up (€/m²)	4,00	4,00	4,00		4,00	4,00	4,00	

Table 4-8 Large Industry application design calculation data

Reference design	BC Taskarea	BC Total	BATLED Taskarea	BATLED Total	BATsmart Taskarea	BATsmart Total
Ref geometry & daylight						
Area code	floor		floor		floor	
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	
total number of luminaires in area(Nlum)	56		70		70	
Classification of daylight availability in area	Strong		Strong		Strong	
Pls (power of lamps in luminaire)	400,00		158,40		158,40	
control gear failure rate per 1000h@70°C(%)	0,20		0,20		0,20	
ηp = fB (power efficiency of luminaire)	0,92		1,00		1,00	
Pi (maximum luminaire power)	434,78		158,40		158,40	
Pn (maximum luminaire power installation total)	24347,83	24347,83	11088,00	11088,00	11088,00	11088,00
Ppc (control power total) (W/m²)		0,00		0,00		0,10
ηls (lm/W) =ηL (25°C standard conditions)	105,00		128,10		128,10	
luminous flux of lamps in luminaire	42000,00	2352000	20291,04	1420373	20291,04	1420373
FLLM (non LED) or Lx from LxBy@life time (LED)	0,91		0,90		0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90		0,99		0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	0,64	0,64	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	61,82		128,10		128,10	
FLM (Luminaire Maintenance Factor)	0,94		0,91		0,91	
constant illumination control(EN 15193)	n		n		y	
occupancy control type(EN 15193)	Man. On/Off		Man. On/Off		Man. On/Off	
room type absence (EN 15193)	Open>sense 30m²		Open>sense 30m²		Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	I: Manual		I: Manual		V: Dim&noSB	
type of blinds control (annex F 3.2.4) (EN 15193)	MO		MO		Auto	
calculated energy performance parameters EN15193 & study defined						
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,85	0,85	0,79	0,79	0,79	0,79
U (utilance) = ηR		1,06		1,18		1,18
overlighting correction on Fcl (dimming scene)	1,00		1,00		1,00	
Fc (constant illumination factor)	1,00		1,00		0,91	
Fo (formula E.1) (occupancy)	1,00		1,00		1,00	
Fd (formula 9) (daylight)	0,54		0,54		0,40	
no standby control losses when unoccupied		y		y		y
LENI [kWh/(m²y)] (f 15) (for controls)		0,00		0,00		0,40
LENI [kWh/(m²y)] (f 15)	11,0	11,0	5,0	5,0	4,0	4,4
ηinst-u [lm/W] (1/specific load)		55,4		119,9		119,9
LPD [W/(100 lx.m²)]		1,8		0,8		0,8
Light source cost per luminaire for repair(= lamp or LED lum.)	20,00		325,00		375,00	
control gear cost per luminaire for repair	50,00		80,00		80,00	
Luminaire unit cost including lamp and control gear	175,00		325,00		375,00	
Extra design mark up (€/m²)	0,00		4,00		4,00	

Table 4-9 Industry workshop application design calculation data

Reference design	BC Taskarea	BC Total	BATLED Taskarea	BATLED Total	BATsmart Taskarea	BATsmart Total	BATbright Taskarea	BATbright Total
Ref geometry & daylight								
Area code	workfloor		workfloor		workfloor		workfloor	
Reflectance ceiling	0,7		0,7		0,84		0,84	
Reflectance Walls	0,5		0,5		0,71		0,71	
Reflectance floor cavity	0,2		0,2		0,2		0,2	
total number of luminaires in area(Nlum)	63		18		18		18	
Classification of daylight availability in area	Strong		Strong		Strong		Strong	
Pls (power of lamps in luminaire)	56,00		77,00		77,00		77,00	
control gear failure rate per 1000h@70°C(%)	0,20		0,20		0,20		0,20	
ηp = fB (power efficiency of luminaire)	0,88		1,00		1,00		1,00	
Pi (maximum luminaire power)	63,64		77,00		77,00		77,00	
Pn (maximum luminaire power installation total)	4009,09	4009,09	1386,00	1386,00	1386,00	1386,00	1386,00	1386,00
Ppc (control power total) (W/m²)		0,00		0,00		0,10		0,10
ηls (lm/W) =ηL (25°C standard conditions)	92,50		117,50		117,50		117,50	
luminous flux of lamps in luminaire	5180,00	326340	9047,50	162855	9047,50	162855	9047,50	162855
FLLM (non LED) or Lx from LxBy@life time (LED)	0,91		0,93		0,93		0,93	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90		0,99		0,99		0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	0,64	0,64	0,98	0,98	0,98	0,98	0,98	0,98
ηluminaire (lm/W)	52,10		115,15		115,15		115,15	
FLM (Luminaire Maintenance Factor)	0,91		0,91		0,91		0,91	
constant illumination control(EN 15193)	n		n		y		y	
occupancy control type(EN 15193)	Man. On/Off		Man. On/Off		Man. On/Off		Man. On/Off	
room type absence (EN 15193)	Open>sense 30m²		Open>sense 30m²		Open>sense 30m²		Open>sense 30m²	
type of daylight control (Table F.16) (EN 15193)	I: Manual		I: Manual		VIII: =VI but no auto on		VIII: =VI but no auto on	
type of blinds control (annex F 3.2.4) (EN 15193)	MO		MO		MO		MO	
calculated energy performance parameters EN15193 & study defined								
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,79	0,79	0,81	0,81	0,81	0,81	0,81	0,81
U (utilance) = ηR		0,93		0,94		0,94		1,05
overlighting correction on Fcl (dimming scene)	1,00		1,00		1,00		0,90	
Fc (constant illumination factor)	1,00		1,00		0,92		0,83	
Fo (formula E.1) (occupancy)	1,00		1,00		1,00		1,00	
Fd (formula 9) (daylight)	0,54		0,54		0,31		0,31	
no standby control losses when unoccupied		y		y		y		y
LENI [kWh/(m²y)] (f 15) (for controls)		0,00		0,00		0,25		0,25
LENI [kWh/(m²y)] (f 15)	14,9	14,9	5,2	5,2	3,1	3,4	2,8	3,1
ηinst-u [lm/W] (1/specific load)		38,6		87,7		87,7		98,4
LPD [W/(100 lx.m²)]		2,6		1,1		1,1		1,0
Light source cost per luminaire for repair(= lamp or LED lum.)	20,00		300,00		350,00		350,00	
control gear cost per luminaire for repair	40,00		50,00		50,00		50,00	
Luminaire unit cost including lamp and control gear	150,00		300,00		350,00		350,00	
Extra design mark up (€/m²)	0,00		4,00		4,00		4,00	

Table 4-10 Warehouse general illumination application design calculation data

Reference design	**BC Taskarea**	**BC Total**	**BATLED Taskarea**	**BATLED Total**	**BATsmart Taskarea**	**BATsmart Total**	**BATday Taskarea**	**BATday Total**
Ref geometry & daylight								
Area code	workfloor		workfloor		workfloor		workfloor	
Reflectance ceiling	0,7		0,7		0,7		0,7	
Reflectance Walls	0,5		0,5		0,5		0,5	
Reflectance floor cavity	0,2		0,2		0,2		0,2	
total number of luminaires in area(Nlum)	624		70		70		70	
Classification of daylight availability in area	None		None		None		Strong	
Pls (power of lamps in luminaire)	28,00		158,40		158,40		158,40	
control gear failure rate per 1000h@70°C(%)	0,20		0,20		0,20		0,20	
ηp = fB (power efficiency of luminaire)	0,88		1,00		1,00		1,00	
Pi (maximum luminaire power)	31,82		158,40		158,40		158,40	
Pn (maximum luminaire power installation total)	19854,55	19854,55	11088,00	11088,00	11088,00	11088,00	11088,00	11088,00
Ppc (control power total) (W/m²)		0,00		0,00		0,10		0,10
ηls (lm/W) =ηL (25°C standard condictions)	92,50		128,10		128,10		128,10	
luminous flux of lamps in luminaire	2590,00	1616160	20291,04	1420373	20291,04	1420373	20291,04	1420373
FLLM (non LED) or Lx from LxBy@life time (LED)	0,91		0,90		0,90		0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90		0,99		0,99		0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	0,91	0,91	1,00	1,00	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	74,07		128,10		128,10		128,10	
FLM (Luminaire Maintenance Factor)	0,91		0,91		0,91		0,91	
constant illumination control(EN 15193)	n		n		y		y	
occupancy control type(EN 15193)	Man. On/Off		Man. On/Off		presence det.		presence det.	
room type absence (EN 15193)	Open>sense 30m²		Open>sense 30m²		Open>sense10m²		Open>sense10m²	
type of daylight control (Table F.16) (EN 15193)	I: Manual		I: Manual		VIII: =VI but no auto on		VIII: =VI but no auto on	
type of blinds control (annex F 3.2.4) (EN 15193)	MO		MO		MO		MO	
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,82	0,82	0,79	0,79	0,79	0,79	0,79	0,79
U (utilance) = ηR		0,83		1,05		1,05		1,05
overlighting correction on Fcl (dimming scene)	1,00		1,00		1,00		1,00	
Fc (constant illumination factor)	1,00		1,00		0,91		0,91	
Fo (formula E.1) (occupancy)	1,00		1,00		0,95		0,95	
Fd (formula 9) (daylight)	1,00		1,00		1,00		0,31	
no standby control losses when unoccupied		y		y		y		y
LENI [kWh/(m²y)] (f 15) (for controls)		0,00		0,00		0,25		0,25
LENI [kWh/(m²y)] (f 15)	11,3	11,3	4,0	4,0	3,4	3,7	1,3	1,6
ηinst-u [lm/W] (1/specific load)		50,4		105,4		105,4		105,4
LPD [W/(100 lx.m²)]		2,0		0,9		0,9		0,9
Light source cost per luminaire for repair(= lamp or LED lum.)	20,00		325,00		375,00		375,00	
control gear cost per luminaire for repair	40,00		80,00		80,00		80,00	
Luminaire unit cost including lamp and control gear	75,00		325,00		375,00		375,00	
Extra design mark up (€/m²)	0,00		4,00		4,00		4,00	

Table 4-11 Warehouse rack application design calculation data

Reference design	BCLED Taskarea	BCLED Total	BATsmart Taskarea	BATsmart Total	BATday Taskarea	BATday Total
Ref geometry & daylight						
Area code	racks		racks		racks	
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	
total number of luminaires in area(Nlum)	25		25		25	
Luminaire code	**LED**		**LED**		**LED**	
Pls (power of lamps in luminaire)	139,00		139,00		139,00	
control gear failure rate per 1000h@70°C(%)	0,20		0,20		0,20	
ηp = fB (power efficiency of luminaire)	1,00		1,00		1,00	
Pi (maximum luminaire power)	139,00		139,00		139,00	
Pn (maximum luminaire power installation total)	3475,00	3475,00	3475,00	3475,00	3475,00	3475,00
Ppc (control power total) (W/m²)		0,00		0,10		0,10
ηls (lm/W) =ηL (25°C standard conditions)	136,40		136,40		136,40	
luminous flux of lamps in luminaire	18960,00	474000	18960,00	474000	18960,00	474000
FLLM (non LED) or Lx from LxBy@life time (LED)	0,90		0,90		0,90	
FLS (non LED) or Cz from LxCz@life time (LED)	0,90		0,99		0,99	
CIE flux code N5(RLO) (Luminaire light output ratio)	1,00	1,00	1,00	1,00	1,00	1,00
ηluminaire (lm/W)	136,40		136,40		136,40	
constant illumination control(EN 15193)	n		y		y	
occupancy control type(EN 15193)	Man. On/Off		presence det.		presence det.	
room type absence (EN 15193)	Storage/Cloakroom		Storage/Cloakroom		Storage/Cloakroom	
type of daylight control (Table F.16) (EN 15193)	I: Manual		I: Manual		VIII: =VI but no auto on	
type of blinds control (annex F 3.2.4) (EN 15193)	MO		MO		MO	
FM = FLLM x FM x FRSM (spot replacement LSF=1)	0,81	0,81	0,81	0,81	0,81	0,81
U (utilance) = ηR		0,28		0,28		0,28
overlighting correction on Fcl (dimming scene)	1,00		1,00		1,00	
Fc (constant illumination factor)	1,00		0,91		0,91	
Fo (formula E.1) (occupancy)	0,30		0,25		0,25	
Fd (formula 9) (daylight)	1,00		1,00		0,31	
no standby control losses when unoccupied		y		y		y
LENI [kWh/(m²y)] (f 15) (for controls)		0,00		0,40		0,40
LENI [kWh/(m²y)] (f 15)	7,0	7,0	5,3	5,7	3,0	3,4
ηinst-u [lm/W] (1/specific load)		30,7		30,7		30,7
LPD [W/(100 lx.m²)]		3,3		3,3		3,3
W/m²		5,8		5,9		5,9
input product performance parameters economic system						
Light source cost per luminaire for repair(= lamp or LED lum.)	100,00		400,00		400,00	
control gear cost per luminaire for repair	80,00		80,00		80,00	
Luminaire unit cost including lamp and control gear	350,00		400,00		400,00	

Summary and discussion:

In general significant savings in the LENI value can be obtained for all applications compared to the base cases; a summary is included in Figure 4-4. It is also worth comparing these LENI values with those derived from the TEK tool in Figure 1-21 or the maximum indicated in the Suisse standard SIA 380/4-2009 in Table 1-8. From this it can be concluded that our ‘base case’ is most often compliant and should not be regarded as the worst case for new installations, nor as being representative of the existing stock. For example the cellular office with ceiling mounted luminaires has a Base Case (BC) LENI calculated at 19 kWh/(m².y) (Table 4-1) which corresponds to the ‘low’ loss class (‘B’) in the IWU TEK tool. The BC cellular office LENI of at 19 kWh/(m².y) is also much below the maximum LENI in the Suisse building code (Norme SIA 380/4:2009), which is 24 kWh/(m².y). For comparison, the best ‘BATbright’ solution for a cellular office had a calculated LENI of only 2,2 kWh/(m².y).

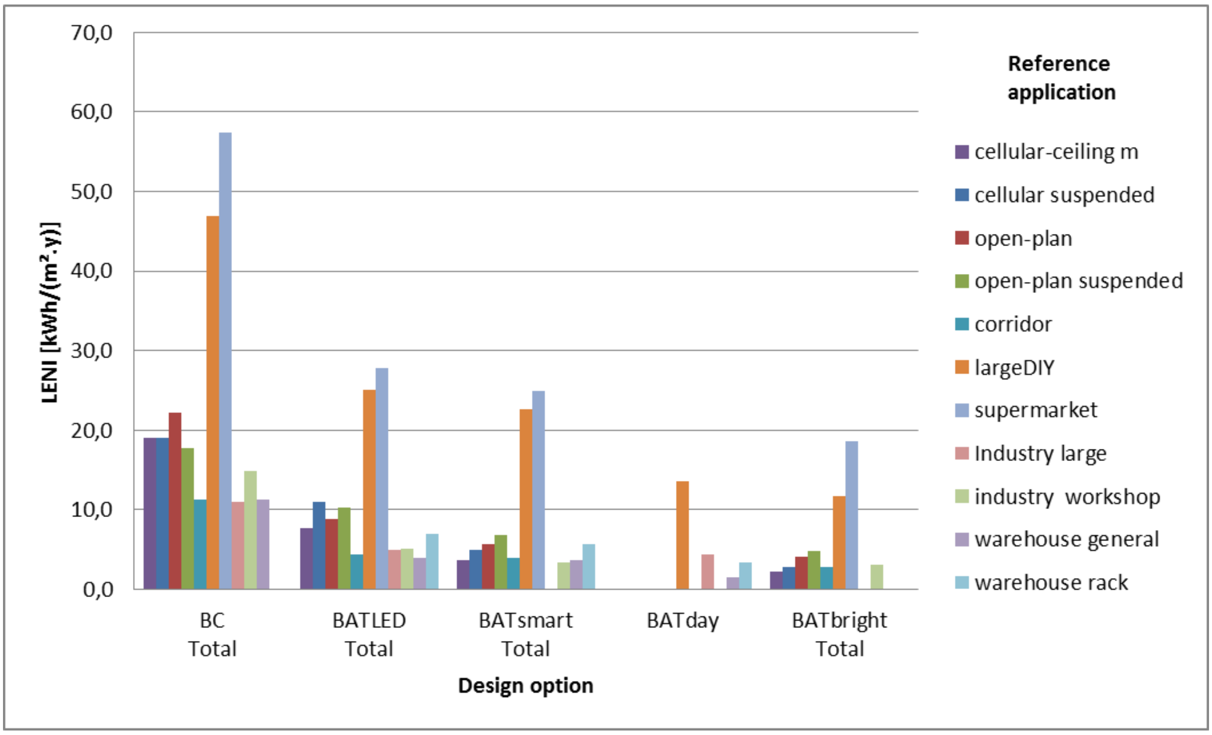


Figure 4-4 Calculated LENI values per reference application for various lighting design options

Looking in more detail at (Figure 4-4) the following observations can be made and conclusions drawn:

- It should be noted that not all design options are considered for all applications. For example options that have windows by default (offices, supermarket) were included in the base case ('BC'). A bright design was not considered for the warehouse and industry workshop case because it is depends on the rack or machinery installed and little on the reflectance of the building surfaces.
- In the case of indoor lighting applications daylight and bright surfaces collectively have a strong impact. Especially in the case where roof lights are used high daylight factors can easily be achieved e.g where they were added in the large DIY reference application. For vertical facades it is more difficult to bring more daylight deep into the building; however, as was calculated in Task 3, bright surfaces help to bring more daylight into the building and to contribute to lower LENI values. In applications where rooflights are possible high daylight contributions can provide large savings. For example they were not part of the BC in 'largeDIY', 'industry large' or 'warehouse' but added as an extra option 'BATday'. In all these daylight dependant control systems, as defined in Task 3, play an important role.
- Better luminaire optics and optical design also contributed to lower LENI values. This is reflected via the higher Utilance (U) values in nearly all the BAT designs. However in the impact of these measures for the indoor lighting applications is not as high as for the road lighting applications. As mentioned before Utilance is only representative for a single design parameter (illuminance on the floor area) and during the design process several other design criteria have to be met such that it is not possible to optimise to this parameter alone. This is especially the case for applications where vertical

illumination requirements are added, such as in retail ('LargeDIY', Supermarket', 'Warehouses' and where the required power density (W/m²) can be relatively high compared to the horizontal illuminance requirement. As a consequence these cases have relatively high LENI values ('LargeDIY', 'Supermarket'). In the case of the high shelfs in the warehouse ('warehouse rack') it was only possible to satisfy the vertical illuminance requirements and uniformity with advanced LED designs, and as a result no base case ('BC') is available for the application 'warehouse rack'.

- All the data details are available to discrimate improvements related to the light source efficacy from other lighting system improvements in the policy scenarios of Task 7.

4.1.2 BNAT for indoor lighting

Approach: In this section on BNAT, or low energy use systems, we discuss the best systems that are under development but not yet at a stage of development which is sufficient to be placed on the market. They could also be used in later sections for assessing the impact of any future policy measures.

Improved lighting design software and optimisation functions:
The lighting design software used for this exercise (Dialux 4.12) does not yet contain the full prEN 15193:2016 calculations, but it is expected that this feature will be added in the future. During the design exercise for Task 4 much of the optimisation work, such as selecting luminaries with appropriate optics, relied on the experience of the lighting designer. Some form of artificial intelligence and/or optimisation algorithms could be developed in line with developments in other technological areas. This could reduce lighting design costs, see Task 2.

Holstic control systems with user feedback:

New systems[202] are entering the market with individually computer controllable luminaires, for example, so that changes in user requirements and/or task area can be implemented quickly and easily without opening suspended ceilings. Furthermore, the luminaires can be equipped with systems allowing an instant and precise localisation of users. Moreover luminaires can be equipped with an additional multi-sensor to detect movement, light, infrared and temperature to enable control of other functions such as HVAC. This data is fed to facility managers via the building management system(BMS) allowing for example:

- remote insight into the presence of people in the building (anonymous). Heating, cooling, fresh air and lighting are fully IoT (Internet of Things) integrated and BMS controlled per zone based on occupancy – with zero occupancy there is next-to-zero energy use.
- predictions of occupancy at lunchtime based on real time historical data and traffic and weather information to avoid food-waste.
- unused rooms to be skipped for cleaning.
- managers to be alerted to lights that need replacing.
- notification of printers needing paper.

[202] http://www.breeam.com/index.jsp?id=804

In general the emergence of the so-called 'Internet of-Things'[203],[204] will facilitate the deployment of smart building controls in the market while stimulating the emergence of new control functions.

Therefore new automation functions can be expected that are not yet covered by the functions cited in prEN 15193:2016. As a result new occupancy (Fo) and daylight factors(Fd) may also be needed, see Task 3.

Human centric lighting:

Apart from the visual function lighting has the power to energise, relax, increase alertness, cognitive performance and mood, and to improve the day-night-rhythm of people[205]. Not all these lighting quality aspects are yet captured in EN 12464-1:2011 and research is ongoing[206] to further define and quantify the lighting quality aspects of these functions. Therefore efforts are ongoing to find better lighting schemes to provide improved visual, biological and emotional benefits. When lighting combines all three benefits it is also referred as human centric lighting. The consequence of this is that more time variable colour and light intensity requirements tend to be specified. This has no impact on the LENI calculation itself but could impact the best values that are achievable compared to the requirements. Nevertheless, it could impact the best LENI limits achievable for a certain application.

4.1.3 Road lighting base case and BAT reference designs

Approach:
In this task the current sales base case (BC) is compared with different BAT design options for each of the reference applications that were previously defined in Task 3. Note that for each reference application an extensive set of lighting requirements are defined in line with EN 13201-2:2016-1, see Chapter 3. All the road lighting designs were conducted using the lighting design software Dialux 6.0[207].

The following design options were elaborated for road lighting:

- 'BC' means the current sales base case, which is a low cost simple design that still satisfies the minimum requirements of EN 13201-2. These designs were created using non-LED products but could of course also be derived with comparable LED products for the purpose of futher modelling in Task 7; all trhe data needed for this is available in the design data files. Note that the base case designs already satisfy the EN 13201-2 requirements and basic design selection rules were applied in their development, hence it is likely that much worse systems may be installed in practice. The base case designs were produced by an experienced lighting designer based on what could be considered a mainstream design using HID technology. Please note therefore, that these are, by far, not the worst systems available and installed on the market today.
- . 'LEDdesign' means the best fit with precisely selected luminaire optics with LED and design practices as supplied by the participating designers from four different lighting manufacturers[196]
- 'LEDsmart is the 'LEDdesign' option but with the best smart controls as defined in EN 13201-5.

[203] http://www.itu.int/en/ITU-T/gsi/iot/Pages/default.aspx
[204] https://en.wikipedia.org/wiki/Internet_of_things
[205] 'licht.wissen 19', 'Impact of Light on Human Beings', http://www.licht.de/de/
[206] http://ssl-erate.eu/work-packages/
[207] https://www.dial.de/en/dialux/download/dialux-evo-download/

First, the 'BC' and 'LEDdesign' cases were established via the lighting design calculations in Dialux. Afterwards optimised designs were supplied in Dialux software by experienced lighting designers from four different lighting manufacturers[208] to help to identify the best possible design and luminaire fit for the reference applications.

Finally, for the 'LEDsmart' cases a calculation spreadsheet was used that is consistent with EN 13201-5:2016 for what could be saved from the use of 'Constant Light Output' control and dimming with parameters t_{full}, t_{red} & k_{red} (see Task 3). For dimming it was assumed that during half the night dimming is possible to the lowest possible level specified in EN 13201-2 at half the nighttime. For example, it assumes that there is a reduced light level during hours of low traffic from class M2 (1 Cd/m²) to class M5 (0.5 Cd/m²) and thus k_{red} = 0.3 when t_{red} = 2000 h. Calculations of AECI and PDI were done in a spreadsheet elaborated for this study but it should be noted that theycan also be directly obtained from the lighting design software (e.g. Dialux EVO 6.0).

Results:
The results of this lighting design exercise and data collection are summarized in the following tables and will be discussed and analysed in the subsequent section.

[208] Members of http://www.lightingeurope.org/

Table 4-12 Road lighting applications with design calculation data

Subcategory for lighting		**Motorways**			**Main or national roads**		
tfull [h/year]		2 000	2 000	*2000*	*2000*	*2000*	*2000*
tred [h/year]		2 000	2 000	*2000*	*2000*	*2000*	*2000*
kred		1	1	*0,3*	*1*	*1*	*0,3*
design		HPS 250 W	LEDdesign	LEDsmart	HPS 150W	LED	LEDsmart
Maximum luminaire power, Pl [W]		270	122	122	170	99	99
Luminaire ref.		brand A type 1	brand A type 2	brand A type 2	brand A type 3	brand A type 4	brand A type 4
Luminous flux (luminaire):		27885	14577	14577	15118	9190	9190
Luminous flux (lamp) (source Dialux):		33200	17280	17280	18000	12006	12006
Boom inclination(°)		0	0	0	0	0	0
Boom length		2	1,5	1,5	0	3	3
Light centre height		14	13,5	13,5	12	10,5	10,5
Light overhang		1	1	1	0	2	2
RULO		0,01	0,00	0,00	0,01	0,00	0,00
Luminous intensity class		G*3	G*3	G*3			
Maintenance factor(FM=FLLMxFLM)		0,82	0,8	0,8	0,8	0,8	0,8
side track 1 class		P2	P2	P2			
Em [lx]		23,79	11,73	11,73			
Emin [lx]		15,39	5,68	5,68			
road zone(s) class		M2	M2	M2	M3	M3	M3
Lm [cd/m²]		2,06	1,59	1,59	1,08	1,16	1,16
Ul		0,75	0,84	0,84	0,67	0,73	0,73
U0		0,67	0,57	0,57	0,59	0,51	0,51
TI [%]		9,54	9,75	9,75	10,09	11,99	11,99
EIR		0,76	0,56	0,56	0,56	0,3	0,3
Em [lx]		30	20,8	20,8	15,29	13,80	13,80
Emin [lx]							
side track 2 class		P2	P2	P2			
Em [lx]		23,79	11,73	11,73			
Emin [lx]		15,39	5,68	5,68			
EN 132015 parameters							
kW/km		10,8	4,88	4,88	6,8	3,96	3,96
PE (AECI) [kWh/(y.m²)]		2,16	0,98	0,39	2,16	1,26	0,51
PD (PDI) [W/lm=W/(lx.m²)]		0,019	0,013	0,013	0,035	0,023	0,023
Constant light output regulation		n	n	y	n	n	y
CL (factor for over-lighting)		1,40	0,97	0,97	1,07	0,97	0,97
total correction CLO on Pl		1,00	1,00	0,62	1,00	1,00	0,62
ηluminaire [lm/W]		103,3	119,5	119,5	88,9	92,8	92,8
Utilance (U)		0,62	0,78	0,78	0,40	0,59	0,59
ηinst [lm/W]		32,1	57,4	57,4	11,3	26,0	26,0
FLS (lamp survival f)		0,94	0,999	0,999	0,94	0,999	0,999
control gear failure rate per 1000h@70°C(%)		0,00	0,20	0,20	0,00	0,20	0,20
Lamp cost per luminaire for repair	€	30,00	200,00	200,00	15,00	200,00	200,00
control gear cost per luminaire for repair	€	50,00	50,00	50,00	50,00	50,00	50,00
Luminaire unit cost	€	400,00	800,00	1000,00	250,00	500,00	600,00

Subcategory for lighting		rural roads or mixed with residential			mixed conflict		
tfull [h/year]		2 000	2 000	*2000*	*2000*	*2000*	*2000*
tred [h/year]		2 000	2 000	*2000*	*2000*	*2000*	*2000*
kred		1	1	*0,5*	*1*	*1*	*0,5*
design		HPS 100W	LED	LEDsmart	HPS 150W	2xLED	LEDsmart
Maximum luminaire power, Pl [W]		118	49,5	49,5	170	93	93
Luminaire ref.		brand B type 1	brand B type 2	brand B type 2	brand C type 1	brand C type 2	brand C type 2
Luminous flux (luminaire):		8923	5517	5517	13037	9671	9671
Luminous flux (lamp) (source Dialux):		10700	5517	5517	17500	9683	9683
Boom inclination(°)		0	0	0	5	0	0
Boom length		3	3	3	1	1	1
Light centre height		10	10	10	10	10	10
Light overhang		1	1,5	1,5	-0,5	-0,5	-0,5
RULO		0,00	0,00	0,00	0,00	0,00	0,00
Luminous intensity class		G*3	G*4	G*4	G*5	G*3	G*3
Maintenance factor(FM=FLLMxFLM)		0,71	0,96	0,96	0,82	0,8	0,8
side track 1 class		P4	P4	P4			
Em [lx]		6,92	5,76	5,76			
Emin [lx]		3,38	3,79	3,79			
road zone(s) class		M4	M4	M4	C3	C3	C3
Lm [cd/m²]		0,87	0,78	0,78			
Ul		0,62	0,59	0,59			
U0		0,73	0,61	0,61	0,52	0,67	0,67
TI [%]		11,84	8,54	8,54			
EIR		0,63	0,37	0,37			
Em [lx]		10,20	11,00	11,00	16,13	16,02	16,02
Emin [lx]							
side track 2 class		P4	P4	P4			
Em [lx]		8,3	8,31	8,31			
Emin [lx]		6,49	5,9	5,9			
EN 132015 parameters							
kW/km		4,72	1,98	1,98	6,8	3,72	3,72
PE (AECI) [kWh/(y.m²)]		1,35	0,57	0,21	2,16	1,18	0,50
PD (PDI) [W/lm=W/(lx.m²)]		0,036	0,014	0,014	0,017	0,009	0,009
Constant light output regulation		n	n	y	n	n	y
CL (factor for over-lighting)		0,95	1,03	1,03	1,08	1,07	1,07
total correction CLO on Pl		1,00	1,00	0,51	1,00	1,00	0,56
ηluminaire [lm/W]		75,6	111,5	111,5	76,7	104,0	104,0
Utilance (U)		0,52	0,65	0,65	0,48	0,65	0,65
ηinst [lm/W]		14,5	45,0	45,0	28,4	70,8	70,8
FLS (lamp survival f)		0,94	0,999	0,999	0,94	0,999	0,999
control gear failure rate per 1000h@70°C(%)		0,00	0,20	0,20	0,00	0,20	0,20
Lamp cost per luminaire for repair	€	15,00	100,00	100,00	15,00	150,00	150,00
control gear cost per luminaire for repair	€	30,00	30,00	30,00	50,00	50,00	50,00
Luminaire unit cost	€	250,00	300,00	350,00	250,00	500,00	600,00

Subcategory for lighting	mixed traffic			Residential streets P4			
tfull [h/year]	2 000	2 000	*2000*	2 000	*2000*	*2000*	*2000*
tred [h/year]	2 000	2 000	*2000*	2 000	*2000*	*2000*	*2000*
kred	1	1	*0,3*	1	*1*	*1*	*0,7*
design	HID 100W	LED	LEDsmart	HPS 50W	LPS 35W	LED	LEDsmart
Maximum luminaire power, Pl [W]	116	54	54	63	46	28,2	28,2
Luminaire ref.	brand C type 3	brand C type 4	brand C type 4	brand B type 3	brand D type 1	brand B type 4	brand B type 4
Luminous flux (luminaire):	8080	5335	5335	3168	3915	2420	2420
Luminous flux (lamp) (source Dialux):	10700	5341	5341	4000	4550	2420	2420
Boom inclination(°)	5	0	0	0	0	0	0
Boom length	1	1	1	2	2	2	2
Light centre height	7	7	7	6	6	6	6
Light overhang	-0,5	-0,5	-0,5	1	2	1	1
RULO	0,00	0,00	0,00	0,00	0,10	0,00	0,00
Luminous intensity class	G*5	G*4	G*4	G*3	/	G*3	G*3
Maintenance factor(FM=FLLMxFLM)	0,82	0,8	0,8	0,71	0,8	0,96	0,96
side track 1 class							
Em [lx]							
Emin [lx]							
road zone(s) class	P2	P2	P2	P4	P4	P4	P4
Lm [cd/m²]							
Ul							
U0							
TI [%]							
EIR							
Em [lx]	13,76	10,34	10,34	5,34	5,01	7,17	7,17
Emin [lx]	3,16	4,21	4,21	1,88	2,31	2,57	2,57
side track 2 class							
Em [lx]							
Emin [lx]							
EN 132015 parameters							
kW/km	4,64	2,16	2,16	2,52	1,84	1,128	1,128
PE (AECI) [kWh/(y.m²)]	1,93	0,90	0,34	1,01	0,74	0,45	0,38
PD (PDI) [W/lm=W/(lx.m²)]	0,035	0,022	0,022	0,047	0,037	0,016	0,016
Constant light output regulation	n	n	y	n	n	n	n
CL (factor for over-lighting)	1,38	1,03	1,03	1,07	1,00	1,43	1,43
total correction CLO on Pl	1,00	1,00	0,58	1,00	1,00	1,00	1,00
ηluminaire [lm/W]	69,7	98,8	98,8	50,3	85,1	85,8	85,8
Utilance (U)	0,50	0,58	0,58	0,59	0,40	0,77	0,77
ηinst [lm/W]	14,2	26,7	26,7	12,6	10,9	49,0	49,0
FLS (lamp survival f)	0,94	0,999	0,999	0,94	0,94	0,999	0,999
control gear failure rate per 1000h@70°C(%)	0,00	0,20	0,20	0,00	0,20	0,20	0,20
Lamp cost per luminaire for repair	15,00	150,00	150,00	15,00	30,00	100,00	100,00
control gear cost per luminaire for repair	50,00	50,00	50,00	30,00	30,00	50,00	50,00
Luminaire unit cost	300,00	400,00	500,00	150,00	120,00	300,00	350,00

Subcategory for lighting			Residential streets M5		
tfull [h/year]	2 000	*2000*	*2000*	2 000	*2000*
tred [h/year]	2 000	*2000*	*2000*	2 000	*2000*
kred	1	*1*	*1*	1	*0,7*
design	HPS 50 W	LED	LPS 2x36W	LED	LEDsmart
Maximum luminaire power, Pl [W]	62	39	79,2	29	29
Luminaire ref.	brand E type 3	brand C type 5	brand D type 2	brand C type 6	brand C type 6
Luminous flux (luminaire):	3752	3927	4063	3069	3069
Luminous flux (lamp) (source Dialux):	4400	3934	5800	3069	3069
Boom inclination(°)	10	0	10	0	0
Boom length	1	1	1	1	1
Light centre height	7	7	7	7	7
Light overhang	1	-0,5	1	0,5	0,5
RULO	0,03	0,00	0,04	0,00	0,00
Luminous intensity class	G,2	G*4	\	D,6	D,6
Maintenance factor(FM=FLLMxFLM)	0,8	0,8	0,8	0,8	0,8
side track 1 class	P5	P5	P5	P5	P5
Em [lx]	6,96	10,07	8,66	7,86	7,86
Emin [lx]	5,76	5,12	4,27	4,24	4,24
road zone(s) class	M5	M5	M5	M5	M5
Lm [cd/m²]	0,58	0,63	0,51	0,64	0,64
Ul	0,63	0,84	0,75	0,48	0,48
U0	0,82	0,5	0,43	0,87	0,87
TI [%]	13,92	9,02	31,1	9,35	9,35
EIR	0,45	0,5	0,52	0,4	0,4
Em [lx]	8,77	10,07	8,1	9,33	9,33
Emin [lx]					
side track 2 class	P5	P5	P5	P5	P5
Em [lx]	4,31	6,14	4,18	4,74	4,74
Emin [lx]	2,56	5,1	3,18	3,66	3,66
EN 132015 parameters					
kW/km	2,48	1,56	3,168	1,16	1,16
PE (AECI) [kWh/(y.m²)]	1,18	0,74	1,51	0,55	0,22
PD (PDI) [W/lm=W/(lx.m²)]	0,038	0,020	0,050	0,016	0,016
Constant light output regulation	n	n	n	n	y
CL (factor for over-lighting)	1,23	1,41	1,13	1,31	1,31
total correction CLO on Pl	1,00	1,00	1,00	1,00	0,46
ηluminaire [lm/W]	60,5	100,7	51,3	105,8	105,8
Utilance (U)	0,55	0,63	0,49	0,72	0,72
ηinst [lm/W]	14,5	32,4	9,9	43,9	43,9
FLS (lamp survival f)	0,94	0,999	0,90	0,999	0,999
control gear failure rate per 1000h@70°C(%)	0,00	0,20	0,20	0,20	0,20
Lamp cost per luminaire for repair	15,00	15,00	30,00	100,00	100,00
control gear cost per luminaire for repair	30,00	30,00	30,00	30,00	30,00
Luminaire unit cost	150,00	300,00	150,00	300,00	350,00

Summary and discussion:

In general significant savings in the PDI [W/(lx.m²)] and AECI [kWh/(y.m²)] values could be obtained for all applications that were analysed when compared to the base cases (BC). A summary is presented in Figure 4-5 and Figure 4-6. It is also worth comparing the AECI values from these analyses with those in given in Annex A for the EN 13201-5:2016 example calculations and typical values of the energy performance indicators. From this it can be concluded that our 'base case' values are close to the best what can be achieved with non-LED solutions. Hence our base case design should not be regarded as the worst case currently available on the market nor as being representative of the exising stock.

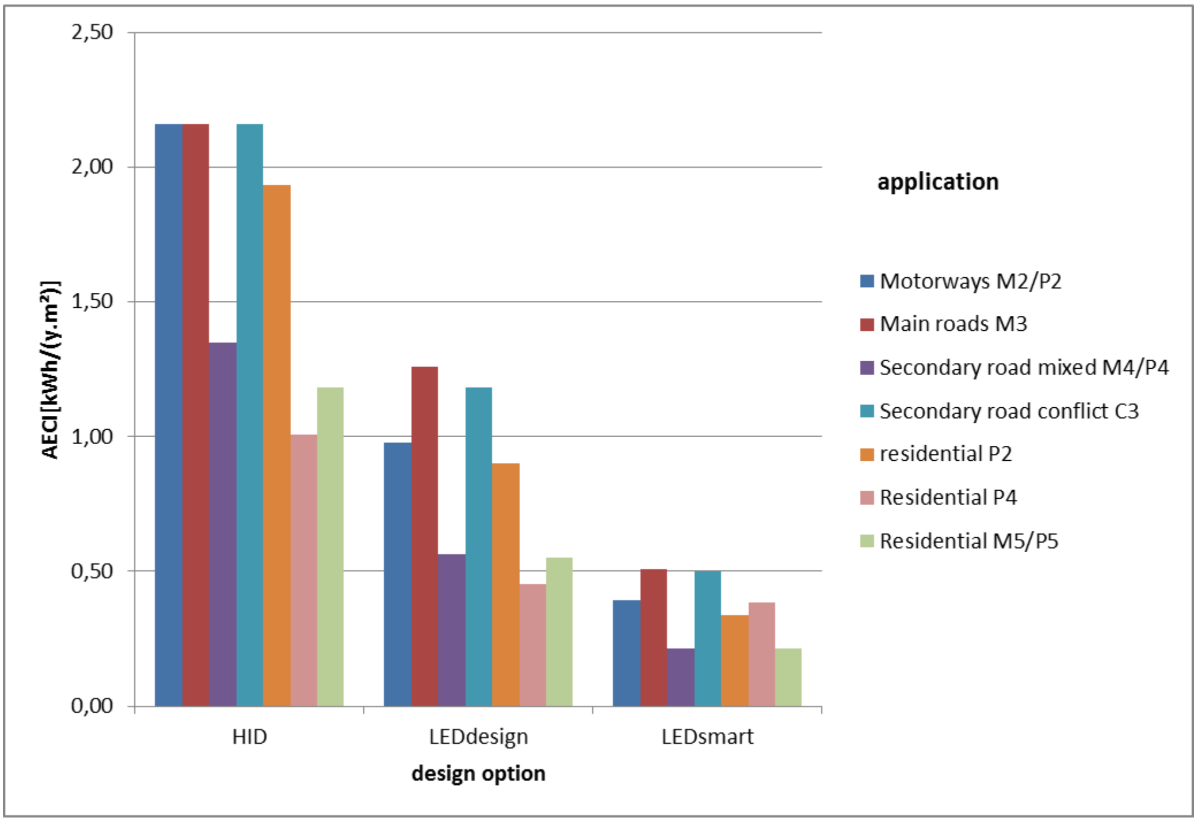


Figure 4-5 Calculated AECI values per reference road for various lighting design options

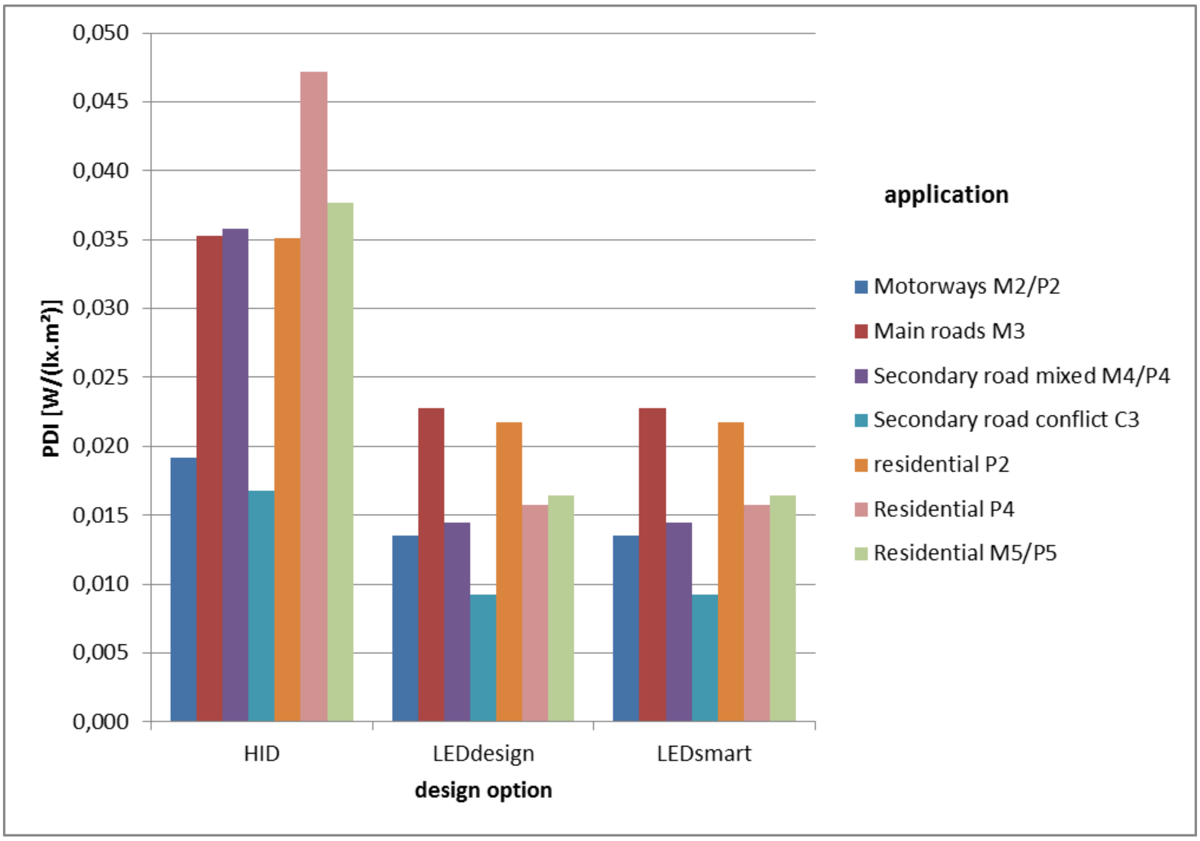


Figure 4-6 Calculated PDI values per reference road for various lighting design options

Looking in more detail into the data and options considered allows the following conclusions to be drawn:

- in all the improvement cases the so-called Utilance' improved. This means that the design and luminaires were more able to direct the light towards the road surface, see Task 3 section 3.2.3.4. This is explained by the greater range of optical light distribution options available today with LED luminaires in combination with lighting design software for their selection.
- Obviously constant illumination control (see section 3.2.3.2.2) that provides constant light output control and compensation for over-illumination by design added in the 'LEDsmart' solution provides additional savings in nearly all the higher efficiency solutions. Therefore smart controls are not necessarily linked to dimming as a function of traffic conditions.

4.1.4 BNAT for road lighting

Better optics for narrow roads:
During the design optimisation excersise it was found that for some narrow road applications (e.g.: Main road M3, Residential P2) we did not obtain the same low PDI values as for larger roads (e.g.: Motorway M2, road with mixed traffic and six lanes(C3)). To a large extent this is due to missing precise optics for this application and it can be expected that such solutions are developed in the future when there is a demand for it..

Improved lighting design software and optimisation functions:

The lighting design software that was used (Dialux EVO 6.0) contained a first implementation of the EN 13201-5 15193 calculations and hence these calculations were relative easy. However during the design exercise for Task 4 much of the optimisation work, such as selecting luminaries with appropriate optics, relied on the experience of the partipating lighting designers. In principle, some form of artificial intelligence and/or optimisation algorthyms could be developed in line with developments in other technological areas. Were this to happen it would reduce the cost of optimised lighting design, see Task 2.

4.2 Production, distribution and End of Life

Objective: The objective of this section is to consider the environmental impacts from the 'production' and 'distribution' of lighting systems. Material flows and collection effort at the 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 the Bill-Of-Materials and the volume of packed material and recycling ratios and methods.

Proposed approach:
Much of the design work 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 rather are disposed of as a set of components. Therefore it is assumed that this is covered by the MELISA model from the Light Sources study[209], see 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.

As a consequence this approach also neglect components when they are not included in the MELISA model , such as wall painting, light poles, cabling, etc. Taking this into account within MELISA would make the analysis very complex without having any indication so far that this would result in applicable and meaningfull policy measures in Task 7.

4.3 Recommendations

There is not a specific LENI limit or AECI & PDI limit that can be put forward as a target, because the best values that can be achieved by design depend on the application and therefore some tolerance might be needed when setting policy targets. Maybe when improved optics and design software tools (see BNAT) enter the market the limit values might be lower and have a reduced application dependent spread. As a consequence in Task 7 a broad range of policy options need to be considered to obtain the BAT per application.

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

CHAPTER 7 SCENARIOS

The Objective

Task 7 builds upon the outcomes of the previous tasks and uses them to inform policy proposal recommendations and to derive Ecodesign impact scenarios which indicate the range of outcomes that might be expected depending on the comprehensiveness of policy packages put into place. Given that the scope of this assessment 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 assessment in this section is simultaneously more limited, yet also broader, than a standard Ecodesign Task 7 assessment. The actions defined for Task 7 under the MEErP can only partly be carried out here because the MEErP Tasks 5 & 6 have not been assessed in this study and cannot inform the policy measure derivation or impact scenarios. Nonetheless some market data of the type that would be derived from these tasks is already available and considered. As a result, the present Task 7 assessment only considers the options of where to go next and provides a basic appraisal of how to implement potential measures. The energy saving potential of the options is considered, but not their full political feasibility. Rather, these options should be addressed further in the course of a full preparatory study.

Summary of Task 7:

Section 7.1 considers the scope of application of potential lighting system measures which fall within the purview of the Ecodesign policy options and scenarios considered in section 7.2/7.3 and section 7.3/7.5 respectively. It proposes scope definitions but also discusses the issue of considering an installed lighting system as a 'product' within the scope of potential Ecodesign measures.

Section 7.2 considers the barriers to lighting system energy efficiency and describes the policy instruments which are available to help address them. It compares policy instruments such the Ecodesign of Energy related Products (ED)(2009/125/EC), Energy Labelling (ELD) (2010/30/EU), Energy Performance in Buildings (EPBD) (2010/31/EU) and the Energy Efficiency Directive (EED) (2012/27/EU).

Section 7.3 puts forward a set of specific policy proposals aimed at improving the environmental and economic performance of lighting systems. Explicitly, the policy measures proposed in section 7.3 consider how new lighting designs can be encouraged to be more in line with best available technology solutions as determined in Task 4 of the report. The measures include a mixture of regulatory requirements, implemented via policy instruments such as Ecodesign Regulations, Building Codes, Highway Codes/ordinances and Energy Labelling regulations; and softer options using incentives, awareness and capacity building measures. Note that product requirements can for example also be a complement to lighting system requirements, e.g. requirements for components such as controls or luminaires to be used in certain type of lighting system.

The impact assessments in sections 7.4 and 7.5 consider the broader impacts of such policy actions and provide a general indication of the costs and benefits they would entail. In a full study, including tasks 5 on Environment & Economics and Task 6 on Design options, the economic optimization and its impact could be more elaborated. Despite these tasks were not performed, the study was able to calculate the potential impact on EU annual energy consumption by linking the improved lighting design techniques of Task 4 to the 'Model for European Light Sources Analysis' (MELISA). The

MELISA model was developed during the Lot 8/9/19 ecodesign preparatory study on light sources[210] and contains the EU reference electricity consumption for lighting. Using MELISA, savings deriving from light source efficiency improvements can be clearly discriminated from savings due to the lighting system improvements investigated in Task 4. The policy measures related to the light source study are still under discussion (October 2016) and hence energy impacts due to lighting system improvements have been evaluated for three reference light source scenarios presented in the Lot 8/9/19 light source study:

- BAU scenario (no new regulations on light sources),
- ECO 80+120 scenario (phase-out of all classical lighting technologies between 2020 and 2024; accelerated adoption of LEDs), and
- ECO 80+120+LBL scenario (same as previous but assuming additional energy labelling improvements; higher average efficacy for LEDs).

The maximum EU-28 total savings for optimised lighting system designs with controls are depending on the reference light source scenario and the maximum EU-28 total annual electricity savings due to lighting system measures are 20-29 TWh/a in 2030 and 48-56 TWh/a in 2050. This is approximately 10% (2030) or 20% (2050) of the total EU-28 electricity consumption for non-residential lighting in the BAU-scenario for light sources.
Because of the long life time of lighting installations, reaching the full impact of lighting system measures will take several decades. The ECO 80+120 light source scenario would accelerate the transition to LED luminaires due to a phase-out of inefficient LFL, CFLni or HID lamp types, and hence would also accelerate the impact of lighting system design and control system policy options proposed in this study. Vice versa, the proposed lighting system measures can also contribute to achieving the energy savings estimated in the light sources study, even without an imposed accelerated switch to LEDs: selection of efficient light sources is anyway necessary to obtain low LENI or AECI values.

The analysis of market data showed that the indoor reference cases of Task 4 covered 63% of the total electricity consumption for indoor non-residential fluorescent lighting and 61% of the total HID-related electricity consumption.

7.1 Scoping of possible policy requirements

Objective

This section describes the prospective boundaries of the scope of policies to address the eco-design performance of lighting systems in terms of the product system types and their boundaries. It informs the consideration of the policy proprosals discussed in section 7.3 and also critically indicates which systems types are not considered to be within the scope of the policies and impacts assessed in this Task.

7.1.1 Considering the scope of indoor lighting technical building system or road lighting systems eligible for policy measures

Indoor lighting systems are technical building systems installed in buildings and are usually not considered as single products brought on to the market, but rather as a composition of products installed by an installer in accordance to the design of a

[210] See: http://ecodesign-lightsources.eu

lighting designer or system specifier. Indoor lighting systems for policy purposes can be defined in line with the scope proposed in Task 1 as *'lighting systems that provide illumination to make objects, persons and scenes visible wherein the system design is based on minimum measurable quality parameters as described in European standard EN 12464-1 on lighting'*.

As discussed in Task 1 (1.3.1) the following types of lighting sytems are excluded from any subsequent policy considerations in this report:

Lighting systems designed for other purposes than providing general illumination based on EN 12464-1, 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 for theatrical, stage, entertainment and similar applications.
- As EN12464-1 does not provide definitive requirements for many commercial areas such as: hospitality, museum and gallery, restaurants, high-end retail etc., these applications are also excluded.
- In general as 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).
- In residential systems the standards EN 12464 and EN 13201 are not applicable and as a consequence they are excluded.

Emergency lighting installations are also excluded because such equipment is already covered with other regulations, has low operating hours and was therefore excluded from previous Ecodesign legislation. The power consumed due to charging of batteries for emergency lighting is also excluded.

Policy measures applicable to, and impacts associated with, power cable losses were defined in the 'Ecodesign preparatory study Lot 8 - Power Cables[211]'. They are not repeated in this analysis but obviously they could be implemented for the case of the power cables used in lighting systems.

The study did not focus on EN 12464-2 related to 'Lighting of work places - Part 2: Outdoor work places', mainly because this is a niche market with limited available data (see Task 2) and there is not yet a complementary standard with efficiency metrics such as EN 15193 or EN 13201-5:2016. Please note that outdoor work places (EN 12464-2) but road lighting was included in this study (EN 13201). were not studied but Therefore policy could first focus on indoor lighting and in a later stage aim to address outdoor lighting via a similar approach.

It is also possible to focus on some application areas with the highest impact. These are the base case applications considered in Task 4 (offices, industry, retail) which are derived using the market data from Task 2. This could be useful were a step by step implementation using tiered policy requirements to be contemplated.

[211] http://erp4cables.net/

Road lighting systems can be defined for further policy measures as a "*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 according to standard EN 13201 on road lighting including similar applications as used for car parks of commercial or industrial outdoor sites and traffic routes in recreational sports or leisure facilities".*

7.1.2 Considering an installed lighting system as a 'product' within the scope of potential Ecodesign measures

At present lighting installations are elements or components of a building and are not currently treated as distinct 'products' in other parts of European legislation. Thus far, none of the EU harmonised Directives have considered whether lighting system designers and/or installers are involved in the "manufacture" or making of the products they install and in consequence no CE marking criteria have yet been specified under the terms of EC Decision (768/2008/EC) on a common framework for the marketing of products in the EEA. Therefore 'designers' and 'installers' are not presently seen to be 'lighting system manufacturers' in any legal sense within EU legislation 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. Lighting system components, such as lamps, control gear (e.g. ballasts) and luminaires are designed and manufactured by members of the same company within a factory and thus clearly fall within the purview of the Ecodesign Directive. Here, it is assumed that lighting systems are legally eligible for the establishment of requirements under the terms of the Ecodesign Directive as our initial assessment shows that *nothing was found to preclude this assumption*. Indeed while the study authors are unaware of fully equivalent cases of the Ecodesign Directive having been applied to non-packaged (i.e. assembled on site) product systems there are already examples of energy labelling regulations being applied to such systems (in the case of domestic boiler packages and domestic water heater packages). Thus within this study, and in accordance with the MEErP, lighting systems are considered as products for which Ecodesign regulatory requirements could be imposed.

7.1.3 Considering whether the full lighting installation, operation and maintenance process falls within the scope

As mentioned in section 3.5.1 of Task 3 it is important to have a full chain of market actors concerned with the development of lighting systems within the scope of prospective policy actions to realise the full projected impacts from the use of the best available technologies identified in Task 4. Ideally that involves all actors in the process from lighting design, installation, commissioning, operation and maintenance as illustrated in Figure 7-1. The extent to which prospective policy measures are actionable for all these stages is considered on a case by case basis in section 7.3. As a consequence to obtain the full impact it is important that policy measures address all these actors and steps to the extent possible. The specific policy instruments that can be used are discussed in later sections, such as implementing measures under the Ecodesign Directive 2009/125/EC, but a variety of policy instruments are likely to be needed.

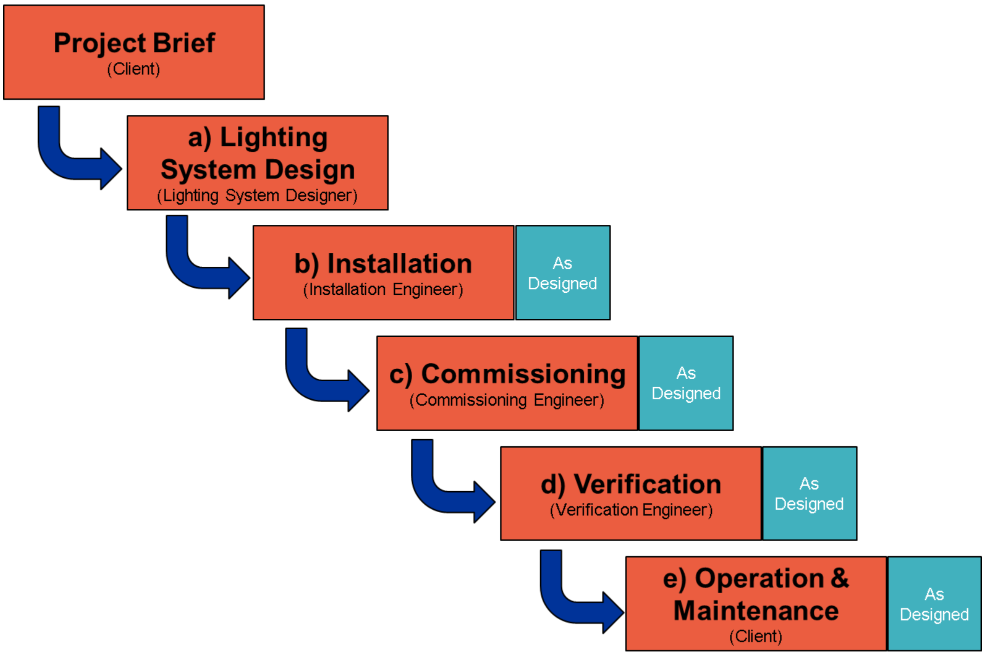


Figure 7-1 Full chain of actors involved from lighting system design until maintenance and operation

7.1.4 Defining the scope of luminaires eligible for product requirements

'Functional luminaires for tertiary lighting' are luminaires intended to be put into service in task areas where minimum illumination requirements are specified in accordance with European Standards, e.g. EN 12464-1 or EN 13201-2. Hence they could be defined as such and made subject to specific product requirements as discussed in section 7.3.7.

'Luminaires not intended for functional tertiary lighting' are the counterpart of the previous category, for example a decorative luminaire for monument lighting. These are luminaires intended for putting into service in areas where no minimum illumination requirements are specified within European Standards, such as for residential or amenity lighting areas. In many cases they have a combined function and lighting controls and/or interfaces can be integrated.

The previous definitions could be used to define the scope of luminaires for use in specific installations, for example a policy measure for office lighting installations according to EN 12464-1 could require that only the *'Functional luminaires for tertiary lighting'* are used.

7.1.5 Defining stand alone lighting controls for product requirements

Standalone lighting controls are *lighting controls installed outside (i.e. separately from) a luminaire* and could include presence detectors, light sensors, switches, wall dimmers, user interfaces etc.

In this context it should be noted that modern lighting controls combine the electromechanical hardware of sensors and luminaires together with ICT hardware such as controllers/outstations, programmers and central facilities such as personal computers (PCs) and data displays. Often they are also integrated with the Building Automation Control System (BACS) and combined with appropriate software within a Building Energy Management System (BEMS). In all this, lighting controls may use the same sensors that could be used for entirely different purposes such as factory automation, e.g. an optical sensor used in food processing. As a consequence, it is recommended to limit the scope of lighting controls considered within any policy framework targeting lighting systems to those declared suitable for this purpose, for example Ecodesign requirements limited to the declared or denominated '*BACS compatible controls*'.

7.2 Barriers to energy efficiency and available policy instruments

Objective:
This section considers the barriers to energy efficiency in lighting systems and reviews the general policy frameworks and instruments that could be applied for the development of specific policy measures. This general discussion is then complemented by the consideration of specific policy measuress to promote the energy performance of lighting systems which are proposed in Section 7.3.

As background for the policy options please also read the summary section from Task 4 that discusses the findings of energy efficiency improvements at the installation level.

7.2.1 Barriers to energy efficient lighting systems

The IEA World Energy Outlook of 2013 presented a discussion of the barriers to energy efficiency in general. These are summarised in Table 7.1 below and from this it can be remarked that all the barriers listed also apply to lighting systems. These include: lack of visibility of the energy performance of lighting systems resulting in undervaluing the opportunity for improvement; lack of priority given to energy savings resulting in undervaluing the techno-economic savings potential; economic barriers notably split incentives (such as landlord-tennant); competing capital needs and unfavourable perceptions of risk; capacity constraints and lack of resources for governments to support implementation of related policy; fragmentation in the lighting supply chain and in the way responsibility for lighting is managed within building energy services or the constructuion sector more generally. Policies are therefore needed to help overcome these barriers. Importantly, some of these barriers operate in series with each other, meaning that if any set of them are addressed but one isn't that this could still be sufficient to prevent progress, thus it is important for designers of policy frameworks to consider these instances and ensure that prospective policy packages are sufficiently comprehensive to effectively overcome them.

Table 7-1 Generic barriers to energy efficiency

	Barrier	Effect	Remedial policy tools
VISIBILITY	EE is not measured	EE is invisible and ignored	Test procedures/measurement protocols/efficiency metrics
	EE is not visible to end users & service procurers	EE is invisible and ignored	Ratings/labels/disclosure/benchmarking/audits/real-time measurement and reporting
PRIORITY	Low awareness of the value proposition among service procurers	EE is undervalued	Awareness-raising and communication efforts
	Energy expenditure is a low priority	EE is bundled-in with more important capital decision factors	Regulation, mechanisms to decouple EE actions from other concerns
ECONOMY	Split incentives	EE is undervalued	Regulation, mechanisms to create EE financing incentives for those not paying all or any of the energy bill
	Scarce investment capital or competing capital needs	Underinvestment in EE	Stimulation of capital supply for EE investments, incubation and support of new EE business and financing models, incentives
	Energy consumption and supply subsidies	Unfavourable market conditions for EE	Removal of subsidies
	Unfavourable perception and treatment of risk	EE project financing cost is inflated, energy price risk under-estimated	Mechanisms to underwrite EE project risk, raise awareness of energy volatility risk, inform/train financial profession
CAPACITY	Limited know-how on implementing energy-saving measures	EE implementation is constrained	Capacity-building programmes
	Limited government resources to support implementation	Barriers addressed more slowly	
FRAGMENTATION	EE is more difficult to implement collectively	Energy consumption is split among many diverse end uses and users	Targeted regulations and other EE enhancement policies and measures
	Separation of energy supply and demand business models	Energy supply favoured over energy service	Favourable regulatory frameworks that reward energy service provision over supply
	Fragmented and under-developed supply chains	Availability of EE is limited and it is more difficult to implement	Market transformation programmes

Abbreviation: EE = energy efficiency.

Source: IEA World Energy Outlook 2013.

7.2.2 Which policy instruments can serve for the proposed policy measures?

As reviewed in Task 1, section 1.5, the EU has four main energy efficiency policy instruments that could influence the energy efficiency of lighting systems:

- The Ecodesign of Energy related Products Directive (ED)(2009/125/EC)
- The Energy Labelling Directive (ELD) (2010/30/EU)
- The Energy Performance in Buildings Directive (EPBD) (2010/31/EU)
- The Energy Efficiency Directive (EED) (2012/27/EU)

The potential applicability of these Directives to lighting systems policy measures is now considered in turn.

7.2.2.1 Ecodesign and energy labelling directives

The Ecodesign Directive (ED) can be used to set minimum eco-design requirements for energy related products that can be either specific or generic in nature. Minimum requirements have traditionally been set for products that are placed on the market as a pre-packaged assembly of components and that meet minimum criteria with respect to the number or products sold, the eco-design improvement potential and cost-effectiveness over the product lifecycle. Specific eco-design requirements are minimum eco-design performance values that products must meet or specific information requirements that must be present at the point of sale. Generic requirements could be specifications regarding processes that have to be followed during the design, manufacture and placing on the market of the product.

The Energy Labelling Directive (ELD) also applies to energy related products and is used to require the energy performance of products to be displayed at the point of sale or placing on the market of the product in question.

Implementing regulations within the ED 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 to this study an Ecodesign study on light sources was conducted http://ecodesign-lightsources.eu/) and obviously large additional savings can be obtained to switch to LED light sources either in retrofit solutions or new luminaires. Policy scenarios for this were proposed and the summary of this study is included Annex N.

Of course lighting systems are generally not sold as a pre-packaged assembly of components but are rather installed on site, often in accordance with a formal lighting design. Their performance is determined by the quality of the design and the performance characteristics of the components from which they are made. The making or "manufacture" of the lighting system thus occurs both where the design process takes place and on the site where the system is installed. Both the commercial entity involved in the design of the product and the entity involved in its installation are thus involved in the making, or manufacture, of the lighting system and thus potentially both could be made subject to requirements under the Ecodesign Directive. Interestingly, although atypical this far, there is already a precedent for imposing requirements on those who design and install domestic heating and hot water systems under the energy labelling Directive. Under energy labelling regulations[212] No 811/2013 and 812/2013 the installers of such systems have to calculate the energy performance of the heating or hot water systems they are proposing to install and present the information to the consumer in the form of a product system-level energy label. To support this process the Commission has developed calculation tools that installers may use to determine the energy performance classification of the systems they are proposing to install[213].

7.2.2.2 Energy Performance in Buildings Directive

[212] See Commission Delegated Regulation (EU) No 811/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of space heaters, combination heaters, packages of space heater, temperature control and solar device and packages of combination heater, temperature control and solar device - OJ L 239, 06.09.2013, p. 1–82 and Commission Delegated Regulation (EU) No 812/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of water heaters, hot water storage tanks and packages of water heater and solar device - OJ L 239, 06.09.2013, p. 83–135

[213] For links in https://ec.europa.eu/energy/sites/ener/files/documents/list_of_enegy_labelling_measures.pdf

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. In practice though 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[214]. Lighting is treated within building Energy Performance Certificates (EPCs) in a similar way – i.e. its energy performance contributes to the overall building energy performance rating but there are no specific requirements for ratings of the lighting system.

Nonetheless it could be argued that if lighting is already incorporated within the whole building energy requirement why does it matter if there are no specific additional requirements? An answer is that lighting is the domain of electrical contractors and/or lighting designers (for higher-end installations). In the absence of specific lighting energy requirements within building 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. Furthermore, even if the project manager is aware of the contribution lighting could make they are unlikely to wish to take the risk that the building whole energy performance approval is dependent on one of the last energy using systems to be installed to satisfy the requirements, and thus lighting is likely to often get a defacto pass from the project manager. It could be argued that having additional and specific minimum legal requirements for lighting system energy performance provides necessary extra assurance that the energy performance of this system will be acceptable. This would help ensure that even in cases where the overall project procurers and managers are unaware of the opportunities lighting can make to whole project energy performance that the lighting system satisfies a minimum level of energy performance. Moreover, energy consumption for lighting can be calculated separately and easiliy metered during life. A separate design value such as LENI or AECI is therefore useful. As a result it will allow the real life LENI or AECI value to be compared with its design value to fine tune control system settings and provide an incentive for any other later improvement.

7.2.2.3 Policy measures in the scope of existing or updated EPBD

The EPBD currently exempts certain building types that still have lighting energy needs, see section 1.5.1.6. In part the specific LENI requirements from later section 7.3.1 could be considered.

In principle the Energy Performance of Buildings Directive could be complemented and/or extended to better address energy savings in lighting systems via:

- More specific and harmonised regulation on the calculation method (EN 15193) used to assess LENI [kWh/(y/m²)] in line with product information required under the Ecodesign Directive;
- Including the maximum LENI for lighting in specific building zones and/or areas in buildings such as in the UK Building regulation part L (see 1.5.1.6);

[214] For requirements on lighting installations in buildings that fall under the Energy Performance of Buildings Directive, see section .

- Specification of minimum building automation functions for lighting in specific building zones and/or areas within buildings, for example a presence detector as in France (RT 2012) (see 1.5.1.6);
- The specification of detailed energy performance certificate information regulation for lighting systems on the calculated and/or measured LENI and some specific system design data behind, for example, Table 10 and 11 in prEN15193:2016);
- The specification of detailed lighting power demand sub-metering requirements in existing or new buildings, see also Method 3 in prEN15193:2016);
- Requirements to retrofit/redesign the lighting installation in those existing buildings with excessive measured or calculated LENI values;
- Extending the scope of the Directive to include the lighting energy performance of building types that are currently exempted from the other provisions of the Directive but where lighting is important (see Task 1).

7.2.2.4 Policy measures in the scope of EED

As mentioned in section 1.5 the Energy Efficiency Directive (EED) has numerous articles which could theoretically be implemented in a manner that would support lighting system efficiency, however, none of them explicitly mention lighting and hence would have to be adapted for that purpose. There are two main ways in which the EED could be used to support lighting system energy efficiency:

- provision of incentives for energy efficient lighting solutions via the energy efficiency obligation measures specified in Article 7 and the energy efficiency national funds specified in Article 20
- provision of professional training to lighting designers/specifiers and installers via the provisions in Article 16

In addition the energy efficiency audit requirements in Article 8 should provide some incentive to energy efficient lighting systems – especially if it triggers the development of meaningful measures for SMEs (which is more discretionary at MS level).

7.2.2.5 Potential standardisation mandates

The study did not focus on EN 12464-2 related to ‘Lighting of work places - Part 2: Outdoor work places’, mainly because this is a niche market with limited available data (see Task 2) and no complementary standard with efficiency metrics, such as are specified in EN 15193 or EN 13201-5:2016, is yet available. Therefore the Commission could issue a mandate to CENELEC to provide a similar standard for EN 12464-2 applications.

As EN12464-1 does not provide definitive requirements for many commercial areas such as: hospitality, museum and gallery, restaurants, high-end retail etc., these applications are also excluded. Also in residential systems the standards EN 12464 and EN 13201 are not applicable and as a consequence these systems are excluded. Were such standards available then in principle the applicability of mimimum lighting design standards and appropriate energy efficiency metrics could also be investigated for these applications.

Also taking into account the need for market surveillance and verification if one should decide on any of the further policy measures it is worth to review, extend and update the measurement procedures in the EN 12464-1 and EN 13201 standards series. In principle and technically speaking all those requirements can be measured but the cost could be high and therefore present a barrier. As a consequence a study could be launched to assess cost effective verification procedures, which might for example result in lower cost procedures but with a larger tolerance.

LENI (EN 15193) and AECI(EN13201-5) calculations rely on lighting design software calculations. So far only technical report CIE 171:2006 provides 'Test Cases to Assess the Accuracy of Lighting Computer Programs'. An update will need to be considered for road lighting because no particular test cases are added for this application. Also, in the context of regulation (if any) one should conclude on the permissible tolerance which is not in the CIE 171:2016 itself.

7.2.2.6 Green Public Procurement (GPP)

On 26 February 2014, the Council of the European Union and the European Parliament adopted two directives aimed at simplifying public procurement procedures and making them more flexible. EU countries have until April 2016 to transpose the new rules into national law (except with regard to e-procurement where the deadline is October 2018).

The old directives (directive 2004/18/EC - the 'classical public sector directive' - and directive 2004/17/EC - the 'utilities directive') are being replaced with the following:

- Directive 2014/24/EU on public procurement, and
- Directive 2014/25/EU on procurement by entities operating in the water, energy, transport and postal services sectors.

The new rules seek to ensure greater inclusion of common societal goals in the procurement process. These goals include environmental protection, social responsibility, innovation, combating climate change, employment, public health and other social and environmental considerations.

In terms of GPP, the following sections of the directives are worth drawing attention to:

- Defining the requirements of a contract: Defining technical specifications is guided through Article 42 and Annex VII of Directive 2014/24/EU; and Article 60 and Annex VIII of Directive 2014/25/EU.
- Use of labels: Conditions for using labels are laid out in Article 43 of Directive 2014/24/EU; and Article 61 of Directive 2014/25/EU.
- Lowest price award and life-cycle costing (LCC): Awarding public contracts on the basis of the most economically advantageous tender is provided as part of Article 67 of Directive 2014/24/EU; and Article 82 of Directive 2014/25/EU.
- Innovation partnerships: Where a contracting authority wishes to purchase goods or services, which are not currently available on the market, it may establish an innovation partnership with one or more partners. This allows for the research and development (R&D), piloting and subsequent purchase of a new product, service or work, by establishing a structured partnership. The procedure for establishing an innovation partnership is set out in Article 31 of Directive 2014/24/EU.
- Consulting the market: The procurement directives specifically allow for preliminary market consultation with suppliers in order to get advice, which may be used in the preparation of the procedure. Article 40 of Directive 2014/24/EU.

In principle MS could develop procurement practices within this rubric that require or favour best practice least life cost or beyond designs in the public sector. Please note that operating in parallel to this study there is an ongoing study[215] on Green Public Procurement for Street Lighting and Traffic Signs. Because VITO is cooperating with JRC, results between both studies are aligned. Note that in principle also indoor lighting in public buildings could be reviewed based on the results and recommendations of this study.

7.2.3 Summary of stakeholder positions

This section contains an overview and summary of the stakeholder positions that were collated following the last stakeholder meeting held before the publication of the Task 7 report.

LightingEurope have released a position paper proposing a Lighting System Design Energy Label as a policy option in the ENER Lot 37 study on lighting systems[216]. This proposal contains the following main elements as now decribed.

The 'lighting system design' shall be regarded as a product and shall contain all information used in the design and information required for the correct installation and operation of the lighting system.

The 'lighting system design' shall be based on criteria for the required illumination for places in the tertiary lighting sector defined in the various EN lighting application standards.

The 'lighting system design' shall include estimation of the energy requirement for lighting and shall indicate by means of labelling the energy efficiency class of the lighting system design.

The 'lighting system design' energy label can be used for all major projects, new or refurbishment, requiring lighting system designs.

Energy labelling of lighting system designs will cover following project segments:
- Office buildings – Business, Communication, Design
- Industry buildings – Manufacture, Warehouse
- Healthcare buildings – Hospitals, Hospice, Residential care
- Retail buildings – Shops, Supermarkets, Wholesales establishments
- Indoor sports facilities and Outdoor sports fields
- Hospitality buildings – Bedded areas, Meeting rooms, Restaurant, Café
- Education buildings – Schools, College, University
- Roads – Traffic routes and conflict areas
- Amenity – Cycle paths, Residential roads, Pedestrian and Amenity areas

'Light quality' and 'energy use' are linked via:
1. Lighting design based on the right EN 'application' standards to secure 'light quality'
2. Calculate the 'energy use' indicator of lighting systems used in the lighting design
3. Check calculated indicator against benchmark value in the EN 'energy use' standard

[215] http://susproc.jrc.ec.europa.eu/Street_lighting_and_Traffic_signs/
[216] http://www.lightingeurope.org/uploads/files/LightingEurope-Position_on_energy_label_for_lighting_system_design-July_2016_.pdf

4. In case calculated value is too high: review design, add additional controls functionality and/or use more efficient products as relevant

Based on 'energy use' calculations for the different project segments, it is possible to create a benchmark table (Annex A - table 2 of the document provides an example where the A to G energy classes are to be defined in terms of LENI limits which may vary depending on the application: Office, Industry, Healthcare, Retail, Sports, Hospitality, Education, Roads, Amenity) where the 'energy use' (in kWh/m^2/year) is linked to an Energy Efficiency Class. In this way it will be possible to assign the lighting system energy efficiency class and put an energy label on a lighting system design.

All new lighting project designs can follow a similar systematic design approach in the execution of the client brief. The collation of project information including the client's brief, concept philosophy, selection of lighting criteria, calculation and planning of the lighting system, production of lighting scheme drawings and assigning of the lighting system energy efficiency class for the project will form the portfolio of the lighting system design.

Verification shall be done by inspection and calculations of the project information portfolio of the lighting system design that the designer shall make available.

Greater details are in the proposal document[217], i.e. 'LIGHTINGEUROPE position on Lighting System Design Energy Label as policy option in the ENER Lot 37 study on lighting systems'.

7.2.4 Could the scope of policy measures be extended to other lighting application areas that were not studied in detail within this study

What are these potential areas?

Apart from road lighting, which is considered in this study, other outdoor lighting applications could also be targeted in future work for example architectural/ monument/facade lighting, parks, industrial outdoor lighting (EN 12464-2), tunnels (guideline CIE 88, country specific standards), sports & recreational facilities (EN 12193), horticulture lighting.
Also residential indoor lighting could be considered, but as explained in Task 1 other metrics would need to be defined and it could be difficult to define quantifiable and measurable illumination metrics especially for 'pieces of art'.

7.3 Consideration of potential policy measures

Objective:
This section describes a set of prospective policy measures which the study team believe would help stimulate the adoption of the best available technology lighting systems options identified in Task 4. As background for the selected policy options please also read the Task 4 summary section that discusses the findings of energy

[217] http://www.lightingeurope.org/uploads/files/LightingEurope-Position_on_energy_label_for_lighting_system_design-July_2016_.pdf

efficiency improvements at the installation level. In each case text is presented that: sets out the rationale for the policy measure, describes the policy measure, considers the pros and cons of the measure, discusses the suitability of the available policy instruments to enable implementation of the measure and provides guidance on the potential timing of the policy measures.

Please also note that this is not a complete assessment because the MEErP Tasks 5 & 6 have not been conducted in this study. In consequence the policy options cannot be ranked based on their impact nor can the optimum levels be defined nor data on economic impacts be made available to support the definition and appraisal of policy measures.

7.3.1 A proposal to require LENI calculations and limits for indoor lighting installations

Rationale

As discussed in chapter 4, the energy efficiency benefits from optimised indoor lighting applications are obtained not only through the adoption of high efficacy luminaires, but also through optimised design options. These can increase the so-called Utilance (U) and daylight contributions (via controls and design), apply occupancy control, and optimise surface reflections within a context wherein minimum task EN 12464-1 requirements are satisfied. Reliance on policy measures which focus solely on light source and luminaire efficacy will result in savings opportunities associated with optimising other aspects of the lighting system design being missed and hence will be sub-optimal; thus, there is a clear rationale to broaden the scope of policy measures to address the performance of the whole lighting system.

In practice, the efficiency of indoor lighting systems is assessed via their LENI value and thus policy measures that address lighting system design efficiency need to be expressed in terms of the LENI value. The LENI captures all the aspects of the lighting system performance, is determined via a recognised European standard and is verifiable by independent inspection. In order to ensure that LENI limits are well adapted to the application requirements, it is appropriate to establish limits that are dependent on those application requirements. These can be done by comparison with available application dependent benchmarks, such as those found in this study. However, to be fully adapted for inclusion in a regulation it is recommended that a full set of application dependent benchmarks be derived, which cover a greater variety of applications. Furthermore, such benchmarks will need to be regularly reviewed to ensure they are still current. This action is especially pertinent given the relatively rapid pace of developments in lighting system technology. Note, there is nothing especially innovative about the establishment of lighting system energy performance limits by application. Among European economies both Switzerland and the UK have done so, while, elsewhere the ASHRAE building codes used in North America also follow this practice.

Proposal

It is proposed to use similar LENI limits to those included in the UK's implementation of the EPBD within part L of the UK building codes, see section 1.5.2.1; however,it is suggested to set the LENI value target at 50 % lower than the current UK values in order to bring them more into line with the study's findings regarding the least life cycle cost efficiency levels. Whenever justified, i.e. in the specific cases where there are particular constraints on vertical or cylindrical illuminance, higher LENI values than these could be accepted. In fact in some cases up to double the proposed LENI values could be considered to be acceptable. This can be concluded from comparing the

reference application[218] designs (BC, BAT) of task 4 with the UK Part L building code LENI limits, see Table 7-2. The current base cases (BC) were derived without the use of LED technology and without applying refined and optimised design strategies. Nonetheless, most of these base case designs comply with the UK Part L building code limits, which indicates these limits are no longer reflective of recent developments in lighting technology. The cases where they did not comply were retail applications with complementary requirements for vertical illumination of retail shelfs. In practice making designs that satisfy these vertical illumination requirements necessitates the use of a skilled lighting designer but also results in over-illumination of the horizontal illumination requirement on the floor. This illustrates why in some cases justified exceptions to LENI limits set at 50% of the current UK Part L limits should be granted. A potential solution is to refine the current UK Part L with some more metrics for frequently occurring application areas within buildings, such as vertical illuminance requirements in retail. This will avoid the situation where many exemptions need to be justified or that higher (sub-optimal) LENI limits have to be used to include them.
Table 7-2 also shows that the Best Available Technology options were able to go far below these limits and that the proposed target set at 50 % of the UK part L requirements can easily be met in most cases. In practice, due to the possibility of particular additional design constraints being present it is not easy to identify a single BAT LENI value that is optimal in all specific cases within a given application. In consequence:

a) BAT LENI values used in regulations need to be set so as to err on the side of caution (i.e. be somewhat weaker than the probable average BAT value for the application in question) to ensure legitimate designs are not excluded;
b) There will be benefit from having complementary policy measures which support the deployment of appropriate lighting systems above the regaultory LENI limit.

Therefore additional complementary policy options should be considered apart from simply calculating the lighting systems LENI value and verifying the application dependent limits are respected.

Table 7-2 also includes power density (W/m²) compared to the US ASHRAE/IES 90.1 2013 limits and the lighting power density relative to the horizontal illuminance. The lighting power density (PDI) relative to the horizontal illuminance (W/(100 lx.m²) is calculated by default by most lighting design software and it is a good indication of the efficacy of the design. Therefore this value could also be requested as complementary information, i.e. in the same way as is requested in standard EN 13201-5:2016 for road lighting.

[218] E.g. cellular office, etc.

Table 7-2 LENI tables comparing the seven reference designs with the UK part L limits (2016) and power density with ASREA/IES 90.1 2013.

	cellular-ceiling mounted		cellular suspended		open-plan ceiling mounted		open-plan suspended	
	BC Total	**BATbright Total**	**BC Total**	**BATbright Total**	**BC Total**	**BATbright Total**	**BC Total**	**BATbright Total**
E,m task area[lx]	≥500	≥500	≥500	≥500	≥500	≥500	≥500	≥500
to (occupied period h/y)	2500	2500	2500	2500	2500	2500	2500	2500
LENI [kWh/(m²y)]	19,0	2,2	19,1	2,8	22,1	4,1	17,7	4,8
ηinst-u [lm/W]	41,6	140,2	49,9	110,3	45,8	170,8	57,4	143,2
LPD [W/(100 lx.m²)]	2,4	0,7	2,0	0,9	2,2	0,6	1,7	0,7
W/m²	12,9	5,2	12,8	7,5	12,6	5,1	10,0	5,9
LENI limit UK part L	20,8	20,8	20,8	20,8	20,8	20,8	20,8	20,8
ASREA/IES 90.1 2013[W/m²]	10,9	10,9	10,9	10,9	10,9	10,9	10,9	10,9

	corridor		largeDIY		supermarket		Industry large	
	BC Total	**BATbright Total**	**BC Total**	**BATbright day Total**	**BC Total**	**BATbright Total**	**BC Total**	**BATsmart Total**
E,m task area[lx]	≥100	≥100	≥300	≥300	≥300	≥300	≥200	≥200
to (occupied period h/y)	2500	2500	4000	4000	4000	4000	4000	4000
LENI [kWh/(m²y)]	11,3	2,8	46,9	11,7	57,3	18,6	11,0	4,4
ηinst-u [lm/W]	16,8	68,3	65,4	129,3	62,6	129,9	55,4	119,9
LPD [W/(100 lx.m²)]	6,0	1,5	1,5	0,8	1,6	0,8	1,8	0,8
W/m²	6,0	2,4	12,2	6,6	14,8	7,3	3,9	1,9
LENI limit UK part L	4,8	4,8	22,7	22,7	22,7	22,7	15,6	15,6
ASREA/IES 90.1 2013[W/m²]	10,9	10,9	9,7	9,7	9,7	9,7	10,9	10,9

	industry workshop		warehouse general		warehouse rack	
	BC Total	**BATbright Total**	**BC Total**	**BATday Total**	**BATLED Total**	**BATday Total**
E,m task area[lx]	≥300	≥300	≥150	≥150	≥150	≥150
to (occupied period h/y)	4000	2500	2500	2500	2500	2500
LENI [kWh/(m²y)]	14,9	3,1	11,3	1,6	7,0	3,4
ηinst-u [lm/W]	38,6	98,4	50,4	105,4	30,7	30,7
LPD [W/(100 lx.m²)]	2,6	1,0	2,0	0,9	3,3	3,3
W/m²	10,2	3,6	2,8	1,7	5,8	5,9
LENI limit UK part L	22,7	22,7	12,0	12,0	20,8	20,8
ASREA/IES 90.1 2013[W/m²]	10,9	10,9	10,9	10,9	10,9	10,9

Pros and cons of proposed policy measure

Imposing legal maximum LENI limits on lighting designs is the surest way of ensuring that new lighting systems will avoid poor energy performance outcomes. The extent to which the limit values would begin to achieve the BAT outcomes identified in Task 4 is dependent on their ambition. On average the BAT shown in Table 7.1 has a LENI value that is 60% lower than a limit value set at 50% of the UK Part L limits, thus doubling the ambition of the UK requirements would still permit designs that are significantly worse than the BAT. Nonetheless the proposal presented here represents a compromise that would prohibit poor designs while being sufficiently flexible to allow legitimate designs to be put forward.

It could be argued that the imposition of LENI limits for indoor lighting constitutes double regulation because lighting is already included in whole bulding or major renovation energy performance requirements (e.g. EN 15603), which all MS have already implemented. However, this ignores the reality of the lighting system supply chain in relation to the delivery of whole building/renovation energy performance targets. When whole project energy performance thresholds are the driver it is likely that decisions will have already been taken to ensure the project meets the required energy performance prior to the lighting being designed or installed, and thus lighting may unintentionally (from a regulatory perspective) get a free pass unless specific performance requirements are imposed for it. The lighting supply chain involves a different set of actors to the rest of the building and the installation of lighting is one of the last actions that occurs before a building is certified to be ready for occupation; thus, in general building project managers will tend to place greater emphasis on managing compliance through measures that occur early in the project than on those actions which occur later to minimise any non-compliance risk.

When considering the pros and cons of LENI as opposed to LPD limit values. It can be argued that LENI limit values, which include the impact of typical application-sensitive usage profiles, are more appropriate than simple lighting power density limits, because they allow the influence of usage profiles to be taken into account and hence can be better optimised in life cycle cost terms. However, it can also be argued that LENI values are somewhat more complex to verify as they require an additional calculation step compared to the LPD, and therefore there is an increased risk they will not be verified in practice. Some jurisdictions, such as Switzerland, addressed this issue by imposing dual LENI and LPD limits (see section 1.5) for which the rationale could be to allow a gateway process towards verification (i.e. if LPD values comfortably satisfy the limits there is less of a risk that the LENI values will not, and hence inspectors may decide to stop at that point for a sample of projects).

Another issue with the imposition of LENI limits is how to manage cases where there is a legitimate need for a design which wouldn't satisfy them. Indeed, as already alluded to above, the art in devising the regulations is to set the values so they are sufficiently ambitious that they will save significant amounts of energy by approaching the BAT solution levels while not being so ambitious that they preclude legitimate design options, at least on a routine basis. Nonetheless it is likely that there will be instances where designs are required with LENI values that exceed the limits and thus a viable process needs to be put in place through which lighting specifiers can seek approval to exceed the regulatory limits providing the supporting evidence is available to justify it, e.g. a declaration of honour[219] from an recognised independent lighting and energy expert.

The other area which would require additional consideration is the process for verifying performance and conducting market surveillance for such product systems. The approach used hitherto for market surveillance of packaged products will not work in the case of non-packaged products which are installed as systems; however, the experience of performance declaration, verification and market surveillance processes that was used for the energy labelling of domestic heating and hot water systems is likely to be adaptable to the needs of lighting systems.

Setting only LENI limits as a policy measure does not necessarily provide an incentive to go much beyond them. In a worst case scenario it could even cause backsliding where designs are only established to meet the limits without considering anything better. Therefore other complementary policy measures, such as life cycle cost calculation and optimisation (see section 7.3.4) or information requirements (see section 7.3.5), could be considered to provide stimulus to go beyond this.

Suitability of policy instruments to implement the proposed policy measure
Building codes, as implemented in line with the EPBD requirements, are the obvious route by which maximum LENI limits can be imposed and/or LENI information and benchmarking can be requested. However, at present this is left entirely at MS

[219] E.g. In the Flemish part of Belgium a Declaration of Honour is required for independent Energy experts in EPBD documentation, http://www.energiesparen.be/epb/prof/eerverklaring

discretion and it could be argued that it is appropriate to amend the provisions in EPBD Article 8 that concern technical building systems to make them more robust for lighting. In particular, so that MS are obliged to specify LENI performace limits in line with the least life cycle cost of the lighting system (i.e. based on a cost optimality approach), just as they are expected to do for other key TBS (heaing, cooling, ventilation).

In addition the EPBD does not:

- cover some building types even though they are as suitable for LENI limits as other building types
- address all instances where new or replacement lighting systems will be installed because its provisions are only required for renovations above a minimum size or proportion of the building area.

These limitations in the field of application remove a lot of lighting system installation events from the current scope and thus, there is a case to be made for the imposition of LENI limits on all new lighting system installations, regardless of whether they occur within renovations or building tyopes addressed by the main provisions of the current Directive.

If MS and the Commission would prefer not to consider the adoption of lighting system LENI limits within building codes, the Ecodesign Directive presents another potential regulatory route. The scope of the Ecodesign Directive does not preclude the specification of application dependent energy performance limits. Furthermore, as both lighting system specifiers and installers are involved in placing the product on the market they could be subject to a collective set of obligations wherein the specifiers (designers) would be required to demonstrate that their design respected LENI limits dependent on the application and the installers would be obligated to demonstrate that the system they have installed meets the specification.

Timing

It is likely that more work would be needed to develop a sufficiently comprehensive set of LENI limit values that are fully adapted to the array of application types found in European buildings. Thus the timing would need to respect this process. Assuming such work could be concluded within 2 years (i.e. by the end of 2018) then either codes using LENI could be adopted within a year of that or a new Ecodesign regulation for lighting systems issued within a year (i.e by the end of 2019). An Ecodesign regulation would typically give market actors at least a year before they would have to comply with the requirements whereas building codes would tend to be immediate. Either way LENI limits could be in place for indoor lighting by the end of 2020. These would then require regular review, thus it is conceivable that further revised tiers could come into force in say 2025 and 2030. A challenge for this is that the available solutions on the market are still improving, see Chapter 4 on BNAT, and that such limits and/or benchmarks will benefit from a continuous update. Therefore the establishment of a centralised database with updated benchmarks for some reference designs could be useful such as the 'Lighting Facts Database' in the US for LED luminaires[220].

7.3.2 A proposal for AECI and PDI calculation and limits in road lighting

Rationale

As discussed in chapter 4, energy efficiency benefits in road lighting cannot only be obtained via a high luminaire efficacy, but also through the use of higher efficiency

[220] http://energy.gov/eere/ssl/led-lighting-facts

designs, e.g. to increase the so-called Utilance (U), encourage adoption of dimming controls and discourage overlighting. Therefore, setting requirements at the design level via the imposition of regulatory AECI & PDI limits would capture a greater proportion of the available techno-economic savings opportunities and result in more economically optimised and environmentally ambitious outcomes than would be achieved from simply focusing on the efficacy of the luminaire and lamps in isolation.

In practice, the efficiency of road lighting systems is assessed via their AECI & PDI value and thus policy measures that address outdoor lighting system design efficiency need to be expressed in terms of these parameters. These capture all the aspects of the lighting system performance, are determined via a recognised European standard and are verifiable via independent inspection. In order to ensure that AECI and PDI limits are well adapted to the specific circumstances (i.e. application) that the lighting design is intended to fulfil it is appropriate to establish limits that are dependent on the application. These can be done by comparison with available application dependent benchmarks, such as those found in this study. However, to be fully adapted for inclusion in a regulation it is recommended that a full set of application dependent benchmarks be derived, which cover a greater variety of applications. Furthermore, such benchmarks will need to be regularly reviewed to ensure they are still current. This action is especially pertinent given the relatively rapid pace of developments in lighting system technology.

Under this proposal AECI and PDI values would need to be calculated to provide insight into the forecast annual energy use of the system and to demonstrate that the lighting system satisfies the maximum limit values. The AECI and PDI values to be applied for such limit values can be compared to benchmarks, such as those supplied in this study, yet would need to be regularly updated to take account of the evolution in the state of art in available lighting system energy performance if they are to remain relevant.

Proposal

Recently, the European standard EN 13201-5:2016 on 'Road lighting- Energy performance indicators' was adopted. This standard provides two unit indicators which are independent of technology, i.e. the Power Density Indicator (PDI) or DP expressed in W/(lx.m²) and the Annual Energy Consumption indicator (AECI) or DE expressed in kWh/(m²y). These two indicators include all sources of component level energy consumption. Therefore, in principle there is no need to set overlapping efficiency requirements for individual components such as lamps and ballasts when designing a new system. Nevertheless, the calculation of these two indicators is based on product data and therefore it will still be necessary to prove that the component performance data is valid when it is to be used within the PDI and AECI calculations.

EN 13201-5:2016 gives guidance on how the PDI unit may be converted for road classes that do not have horizontal illuminance requirements, such as the M and SC road classes i.e. the road classes for motorways or pedestrian areas used in some Nordic countries. The proposed illuminance conversion formulas are:

- For road lighting where luminance ($\bar{L}$,m) is used instead of illuminance (E,m), the following conversion formula can be used, assuming a reference asphalt reflection coefficient: Em = $\bar{L}$m/0.07
- For road lighting where hemispherical illuminance (Ehs) is used instead of illuminance (E,m), the following conversion formula can be used (see also in EN 13201-5): Em,min = Ehs/0.65

It should be noted that 1 W/(lx.m²), i.e. the unit of PDI, is equivalent to 1 W/lm which is the reciprocal value of the installation efficacy in lm/W. The PDI indicator does not take dimming and/or over-lighting into account; however, both are taken into account in the AECI indicator. Therefore, it is recommended to use both indicators together when setting regulatory requirements.

Annex A of EN 13201-5:2016 gives examples of the calculations and typical energy performance indicator values that reflected the state of the art for lighting products (luminaires) as was the case in Q1/2014, see values in Table 7-3 and Table 7-4. The energy performance of LED luminaires were already shown to be superior to all other technologies at that time and have been developing further since.

Table 7-3 Selection of typical values of the Power Density Indicator (PDI)[mW/(lx.m²)] for various road profiles in Annex A of EN 13201-5:2016 compared to similar recent calculated reference designs 'lot 37 BAT' in Task 4 and with formula 161/RW

	Width of carriage way(RW)	**Lamp type**								
road class	**m**	**HPM**	**MH**	**HPS non-clear**	**HPS clear**	**LED**	**Best**	**Task 4 ref. appl.**	**lot37 BAT**	**calculated 161/RW**
road profile A									factor=	161
M2	7	100	50		31 - 40	24 - 27	24			23.0
M3	10	85	42	43	31 - 32	25 - 27	25	**M2**[*]	13	16.1
	8	83	42	40	30 - 33	27	27			20.1
	7	84	47	40	34 - 38	23 - 25	23	**M3**	23	23.0
	6	103	51	43	40 - 44	25 - 28	25			26.8
M4	7	90	60	41 - 47	34 - 42	23	23			23.0
M5	7	86	30	47	38 - 45	24	24			23.0
	6	89	34	53	41 - 51	28	28			26.8
	5	97	41		53	38	38			32.2
	4	116	48		65	46	46			40.3
road profile B										
C3	10	98	44	43	32	18 - 23	18	**C3**	9	16.1
	7	92	51	39 - 45	35 - 41	24	24	**P2**[$]	22	23.0
	6	103	57	48	43	25 - 28	25			26.8
C5	7	95	29	60	44 - 53	27	27	**P4**[*]	16	23.0
	6	107	36	69	50 - 60	31	31			26.8
	5	110 - 125	43		53 - 59	41	41			32.2
road profile E										
M3/P3	10	61	34	29	24 - 33	17 - 18	17			16.1
M4/P4	10	65	41	33 - 34	26 - 28	17	17	**M4/P4**	14	16.1
M5/P5	10	63	22	33	28 - 32	17	17	**M5/P5**	16	16.1

*. Note that the EN standard does not contain reference values for all combinations and also not for all Lot 37 reference applications. Therefore the reference applications are compared to what is considered the most identical in the EN standard.

Table 7-4 Typical values of the Annual Energy Consumption Indicator AECI in kWh/m² for various road profiles in Annex A of EN 13201-5:2016 compared to Task 4 reference designs 'lot 37 BAT' and values calculated values with formula '1,1x161/RWx E,mx0,004'

	Width of carriage way (RW)	**Lamp type**								**Calculated 1,1x161/RWx E,mx0,004**	
road class	**m**	**HP M**	**MH**	**HPS non-clear**	**HPS clear**	**LED**	**EN13201 BAT**	**Task 4 ref. appl.**	**lot37 BAT**	**E,m min [lx]**	**AECI calculated**
road profile A											
M2	**7**	**10,8**	**4,6**		**3,2 - 4,2**	**2,4 - 2,5**	**2,4**			**21,4**	**2,2**
M3	**10**	**6,0**	**3,4**	**3,0**	**2,3**	**1,6**	**1,6**	**M2***	**0,39**	**14,3**	**1,0**
	8	**6,0**	**3,4**	**3,0**	**2,2 - 2,4**	**1,6**	**1,6**			**14,3**	**1,3**
	7	**6,0**	**3,6**	**2,8 - 3,1**	**2,5 - 2,6**	**1,5**	**1,5**	**M3**	**0,51**	**14,3**	**1,4**
	6	**7,0**	**3,9**	**3,2**	**2,7 - 2,8**	**1,6**	**1,6**			**14,3**	**1,7**
M4	**7**	**5,0**	**3,1**	**2,3 - 2,5**	**1,8 - 2,4**	**1,1**	**1,1**			**10,6**	**1,1**
M5	**7**	**3,2**	**0,9**	**1,7**	**1,1 - 1,6**	**0,8**	**0,8**			**7,1**	**0,7**
	6	**3,4**	**1,0**	**2,0**	**1,2 - 1,7**	**0,9**	**0,9**			**7,1**	**0,8**
	5	**3,6 - 4,0**	**1,2**		**1,5 - 1,8**	**1,0**	**1,0**			**7,1**	**1,0**
	4	**4,1**	**1,5**		**1,7 - 2,3**	**1,3**	**1,3**			**7,1**	**1,3**
road profile B											
C3	**10**	**6,0**	**2,7**	**3,1**	**1,9 – 2,0**	**1,1 - 1,4**	**1,1**	**C3**	**0,5**	**15,0**	**1,1**
	7	**5,6**	**3,2**	**2,6 - 3,1**	**2,2 - 2,6**	**1,5 - 1,6**	**1,5**	**P2***	**0,34**	**15,0**	**1,5**
	6	**6,3**	**3,8**	**3,0**	**2,6**	**1,6 - 1,8**	**1,6**			**15,0**	**1,8**
C5	**7**	**3,0**	**0,9**	**1,8**	**1,3 - 1,6**	**0,8**	**0,8**	**P4***	**0,38**	**7,5**	**0,8**
	6	**3,3**	**1,1**	**2,1**	**1,6 - 1,8**	**1,0**	**1,0**			**7,5**	**0,9**
	5	**3,8**	**1,4**		**1,8 - 1,9**	**1,3**	**1,3**			**7,5**	**1,1**
road profile E											
M3/P3	**10**	**3,8**	**2,3**	**1,8 – 2,0**	**1,6**	**1,0**	**1,0**			**14,3**	**1,0**
M4/P4	**10**	**3,2**	**2,0**	**1,5**	**1,2 - 1,5**	**0,7**	**0,7**	**M4/P4**	**0,21**	**10,6**	**0,7**
M5/P5	**10**	**2,0**	**0,6**	**1,0**	**0,7 - 1**	**0,5**	**0,5**	**M5/P5**	**0,22**	**7,1**	**0,5**

* Note that the EN standard does not contain reference values for all combinations and also not for all Lot 37 reference applications. Therefore the reference applications are compared to what is considered the most identical in the EN standard.

PDI:

The best PDI values obtained in the given conditions were 0.017 W/lm or 58 lm/W which is superior to the current GPP criteria. For LED technology, the PDI values in the standard show that they do not or little depend on the road illuminance requirements or road class (see also Table 7-3). Therefore it can be concluded that for LED technology there is no rationale anymore to link PDI requirements to lamp wattage/lumen and/or road illuminance. The main difference between the PDI values in the standard relate to the road width (RW), especially for narrow roads (< 7m). The fact that currently for narrow roads the PDI values are rather high could be attributed to a lack of optics directing the light precisely to the intended road surface.

In Task 4 seven reference road applications were analysed in detail, see section 4.1.3. The reference applications corresponded to a motorway class M2, a national road class M3, a secondary rural roads class M4, a secondary road with mixed traffic class C3, a residential street class P2, a residential street class P4 and a residential street class M5/P5. The best values obtained in Task 4 for PDI for these applications are indicated as 'Lot 37 BAT' in Table 7-3. These values can also be compared to the best values in the EN 13201-5:2016 standard and are indicated as 'Best EN standard'. The difference between the column 'Lot 37 BAT' and 'Best EN standard' can be interpreted as a development of LED technology and design optimization practices for road lighting from Q1/2014 to Q2/2016 and are mainly due to increased LED luminaire efficacies[221] in that time frame (Q1/20014 vs Q2/2016).

Given the observed correlation between PDI and road width a fitting was made to use a simple formula instead of using tables with complementary interpolations. The fitting was done according to road class M3 with a road width of 7 meter and is indicated as '161/RW' in Table 7-3. In general, this fitting relationship shows a lower value for the PDI indicator comparing with the (best) standard EN13201:5 values, but higher than the 'lot 37 BAT' which can be seen as the best on the market currently.

The proposed formula to define a criterion for the PDI value could therefore be:

> PDI [mW/(lx.m²)] = 161/RW[m]
>
> With,
>
> RW[m] is the total width of the road including emergency lanes, sidewalks and cycle lanes when they are in the target area. A minimum of 5 m and a maximum of 10 m shall be used.

For setting minimum PDI requirements correction factors can be applied to the previous formula, e.g. 1,1 resulting in PDI [mW/(lx.m²)] < 11 x 161/RW[m].

Comparing different designs and road layouts from Task 4, it can also be concluded that not only the road width is important, but also the luminaire arrangement and road profile. For example, it has shown evident that a better utilance can be achieved with central luminaire arrangement or long boom angles. Such an arrangement is however not always possible for several reasons such as safety and local conditions (e.g. infrastructure such as centerbeam). These design optimisations are location dependent and should be taken into account when defining criteria using the PDI value based on this fitting approach. Moreover, a deviation could be allowed if particular (local) constraints hinder the implementation of the most efficient design. This shows that full optimisations need to be analysed case by case and provides a strong argument for life cycle costing or similarly total cost of ownership analysis.

AECI:

Not only the PDI value is important in lighting system design, but also the AECI indicator which is expressed in kWh/(m².y). Unlike the PDI indicator the AECI indicator does take into account dimming, over-lighting and a constant light output (CLO) regulation system (see EN 13201-5:2016 and Chapter 4).

[221] For more information on recent progress in LED efficacy see: DOE, 2016. 'US Department of Energy - Solid-State Lighting R&D Plan June 2016' http://energy.gov/sites/prod/files/2016/06/f32/ssl_rd-plan_jun2016_2.pdf (accessed 30 August 2016)

In a worst case scenario with full power all night (i.e. around 11h/day ≈ 4 000 h/y) the AECI [Wh/(m².y)] is related to PDI by the following formula:

AECI [Wh/(y.m²)] = CL x PDI[W/lm]x E,m[lx] x 4 000 h/y

With,

CL the factor to compensate for over-dimensioning compared to the minimum requirements;
E,m the minimum average maintained illuminance according to the road class defined in EN 13201-2:2016. For road lighting where luminance ($\bar{L}$,m) is used instead of illuminance (E,m), the conversion formulas from EN 13201-5:2016 should be used.
PDI can be sourced from the previous formula, i.e. PDI [mW/(lx.m²)] = 161/RW[m]

When comparing the PDI values with the AECI values in Annex A of EN 13201-5:2016 it can be observed that for CL factor of 1.1 can or was used. These means also that AECI values in Annex A did not assume dimming. Setting the CL factor below 1 requires the installation to dim. Column 'Lot37 BAT' in Table 7-4 shows the AECI values obtained in Task 4 that applied amongst others dimming scenarios. In Task 4 dimming is assumed to the lowest class or maximum two classes lower of EN 13201-2:2016 (e.g. class M4 to M6 or M5 to M6) during half the night (i.e. 2000 h/y). As a consequence, more ambitious minimum criteria could be developed for the minimum AECI by setting CL values below 1,1 (e.g. 0,75) or applying a corresponding correction factor to it.

Pros and cons of proposed policy measure
Imposing maximum permitted PDI and AECI limits on road lighting designs is the surest way of ensuring that new lighting systems will avoid poor energy performance outcomes. The extent to which the limit values would begin to achieve the BAT outcomes identified in Task 4 is dependent on their ambition. The average BAT PDI value shown in Table 7.2 is 64% lower than the average proposed regulatory limits. It is debatable whether such a large margin is necessary for roadway lighting and hence there could be an argument to make the proposal more stringent (perhaps in a second tier of requirements). Nonetheless the proposal presented would prohibit poor designs without being so inflexible as to risk precluding potentially legitimate designs.

Note, that for road lighting both AECI and PDI requirements are proposed wherein PDI is the equivalent of Lighting Power Density(LPD) indoor as discussed in section 7.3.1 and included in ASHREA buildings codes (section 1.4.3.3). Thus in road lighting a dual limit approach could provide a double gateway approach to verification.

Another issue with the imposition of AECI and PDI limits is how to manage cases where there may be a legitimate need for a design which wouldn't satisfy them. Indeed, as already alluded to above, the art is to set the limit values so they are sufficiently ambitious that they will save significant amounts of energy and approach the BAT solution levels while being sufficiently lax as to avoid precluding legitimate design options, at least on a routine basis. When such designs are required a viable process needs to be put in place through which specifiers could seek approval providing the supporting evidence justifies it.

The other area which would require additional consideration is the process for verifying performance and conducting market surveillance for such product systems. The approach used hitherto for market surveillance of packaged products within Ecodesign regulations will not work in the case of non-packaged products which are installed as systems; however, the experience of performance declaration, verification and market surveillance processes that was used for the energy labelling of domestic heating and hot water systems is likely to be adaptable to the needs of lighting systems.

Suitability of policy instruments to implement the proposed policy measure
National highway codes or national decrees, could be used as a legislative instrument to implement these requirements; however, at present this is left entirely at MS discretion and it might be argued that there is a need for EU legislation to take the initiative and ensure systematic action. For example Italy has implemented a draft of EN 13201-5:2016 into its decree of the 23th December 2013 (see 1.5.2.2).

The Ecodesign Directive, presents another potential regulatory route. The scope of the Ecodesign Directive does not preclude the specification of application dependent energy performance limits. Furthermore, as both roadway lighting system specifiers and installers are involved in placing the product on the market they could be subject to a collective set of obligations wherein the specifiers (designers) would be required to demonstrate that their design respected PDI and AECI limits dependent on the application and the installers would be obligated to demonstrate that the system they have installed meets the specification.

Timing
The policy will only be applied to lighting systems for which there is a clear net benefit, *to be analysed in a full study including Task 6*.
It is likely that more work would be needed to develop a sufficiently comprehensive set of PDI and AECI limit values that are sufficiently well adapted to the array of roadway application types found across the EU. Thus the timing would need to respect this process. Assuming such work could be concluded within 2 years (i.e. by the end of 2018) then new Ecodesign regulations for roadway lighting systems could be issued within a year (i.e by the end of 2019). An Ecodesign regulation would typically give market actors at least a year before they would have to comply with the requirements such that minimum performance limits could be in place for roadway lighting by the end of 2020. These would then require regular review thus it is conceivable revised limits could come into force in say 2025 and 2030. A challenge for this is that the available solutions for road lighting on the market are still improving, see Chapter 4 on BNAT, and that such limits and/or benchmarks will benefit from a continuous update. Therefore a centralized database with updated benchmark for some reference designs could be useful such as the 'Lighting Facts Database' in the US for LED luminaires[222].

7.3.3 Policy measures for the use of qualified personnel

Rationale
In order to design, install and operate good lighting installations expertise is required concerning the state of art available on the market, EN standards, lighting design software and installation practices. Each of these requires a skill set to be in place and therefore there is a need to both increase the supply of qualified professionals and

[222] http://energy.gov/eere/ssl/led-lighting-facts

raise the level of proof of professional competence required to be a legitimate practitioner.

Proposal
Where a new or renovated lighting systems are being designed, or installed, the party responsible for the implementation of the project shall demonstrate that the design or installation is undertaken by qualified personnel. The nature of qualifications required remain to be determined and are likely to vary by Member State but they could pertain to: a) a minimum number of years of experience, b) having a suitable professional qualification in electrical or building services engineering, c) membership of a professional body in the field of lighting, d) being certified to perform the service in question by an accredited certification body. The level of qualifications required should increase the more substantial the size of the project is, thus, there should be a greater burden of evidence regarding qualifications for those dealing with substantial service sector or public lighting projects.

Pros and cons of proposed policy measure
Establishing minimum and verifiable qualifications among professional lighting designers/specifiers and installers will help to raise the competence of those providing this service to ensure they are capable of designing/installing energy efficient solutions that meet the customers needs and are in line with accepted standards. This will increase the energy savings delivered and reduce poor outcomes both from a lighting quality and energy performance perspective. Certification and accrediation of such professional qualifications is the type of activity that can be supported by measures required under the EED article 16 addressing the Availability of qualification, accreditation and certification schemes. On the other hand, establishing such schemes takes resources from both the private sector and government and these are constrained. It also could be argued that this increases the administrative burden of doing business and may increase customer (initial) procurement costs, but on the other hand this is equally likely to lower referral and correction costs by raising competence and hence there may even be a net procurement cost reduction.

Suitability of policy instruments to implement the proposed policy measure
As mentioned above the aspects of this policy which concern training, certification and accreditation are compatible with the provisions of EED article 16. Local ordinances and similar regulations can be used to impose professional qualification requirements on lighting system practitioners.

Timing
This measure could be initiated very rapidly by Member States but is likely to take some time to fully scope out and put into place at the national level. Most likely qualification schemes could be established first (say by 2018), followed by certification and accreditation requirements faced in progressively beginning with the largest projects from 2019 onwards.

7.3.4 A proposal for LENI or AECI optimisation through least life cycle cost calculation

Rationale
The proposals outlined in sections 7.3.1 and 7.3.2 advocated the setting of maximum LENI and AECI limits for indoor and roadway lighting respectively but provide no incentive to go beyond them. Because these limits need to give enough flexibility so as avoid preclusion of all but the most uncommon situations where there can be a legitimate need to exceed the regulatory limits (in which case an alternative

compliance pathway is proposed) on average the proposed regulatory limits fall someway short of the least life cycle cost lighting design options. Therefore there is still a need to encourage the adoption of lighting systems designs which are in line with the least life cycle cost. This can be supported through the imposition of measures that require a techno-economic assessment of the proposed lighting system as an inout into a least life cycle cost orientated procurement process. Such calculations would make use of the methods in the EN 15193 & EN 13201-5 standards (see also standard CIE 115 for outdoor lighting).

Proposal

Tenderers shall present life-cycle costs for the planned lighting system installation. The designed installation shall also be compared to the existing installation (if any) and at least one more solution. An analysis of the choice shall be presented. The operation and maintenance plan shall be taken into consideration in the calculation. In order to have open and fair competition the tenderer shall specify the input parameters and calculation method to be used (e.g. standard CIE 115). LCC calculations should be clearly presented in a spreadsheet including the input parameters, such as: the cost of labour, the amount of man-hours, electricity costs, variable costs, purchase price, the expected life time of luminaires, PWF (present worth factor), maintenance costs (time to clean a luminaire in group cleaning, time to repair a luminaire in spot replacement, frequency for luminaire cleaning, etc.).

Pros and cons of proposed policy measure

Measures to encourage the inclusion of life cycle costing in tendering will clarify the value proposition of efficient lighting systems to service procurers and hence can be a major stimulus to demand of more efficient systems. Were this practice to be made more systematic it would lead to considerable energy savings and would reward more sophisticated service provision that better reflects the real value of the service provided. The cons concern the practical constraints on how rapidly such service requirements can be rolled out and these are tied to the choice of delivery instrument (discussed in the next section) and the maturity of the supply chain. They also concern the value of the potential energy savings compared to the administrative costs of following life cycle cost related tendering and hence would probably need to be promoted more forcefully for applications where there are likely to be high net benefits compared to those with lower net benefits.

Suitability of policy instruments to implement the proposed policy measure

Stimulus for increased adoption of life cycle cost orientated service offering and tendering could be driven by:

- regulations that require such practices
- green public procurement
- promotion of good energy management practice
- incentives
- awareness raising among procurers

It is likely that regulatory pathways are appropriate for the more energy intensive lighting applications and these could be specified either via local/national level ordinances or potentially via generic Ecodesign regulations that impose requirements on the specification of lighting systems as a function of the application that systems are to be specified for. In principle mandatory generic specification requirements could be rolled out progressively, beginning with the most energy intensive applications. This would allow the lighting service sector to develop the required competences progressively and help drive transformation in the sector. GPP options are discussed in section 7.2.1.6 and could be specified in such a way as to require life cycle costing orientated tendering as set out above. Such specifications, would again drive demand in the public sector and hence could act as a precursor to trial the approach and prime the market ahead of the adoption of more systematic regulations. Incentives, perhaps provided through the Energy Supplier Energy Efficiency Obligation schemes of EED Article 7 or related instruments, could be offered on an installation pro rata basis to suppliers of lighting systems that can demonstrate that their design solutions follow a least life cycle cost procurement process. This would remove first cost barrirrs, lower risk and help expand the development of a competent supply chain. It could also be tied to proof of attainment of professional qualifications and/or certification and accreditation processes (see section 7.2.1.3). Awareness raising is the softest means of encouraging the adoption of such project specification and tendering processes and can be encouraged through communication vehicles that target both procurers and suppliers. In all of the above it will be important to ensure that commonly agreed procedures and guidelines have been developed and promoted.

Timing

A common set of European guidelines on how to specify and procure least cost lighting solutuions could be developed over a 2 year period. The standard CIE 115:2010 already describes an LCC calculation method. Simultaneously work could be conducted to establish precisely which lighting applications should be targeted and in what order, so that generic Ecodesign requirements could be developed that would first apply to the most beneficial applications and then be added to in future stages in order of the net benefit of the application areas considered. The staging could be for generic Ecodesign requirements to be specified for the first set of applications by early 2020 with successive tier(s) to follow 3 years afterwards. GPP guidelines could be established at EU level within 2 years and implemented at MS level within 3 years. EED Article 7 incentives (staged progressively for solutions that exceed LLCC efficiency levels) could also be rolled out within 3 years and make use of the common guidelines.

7.3.5 A proposal for information and documentation requirements at the design stage including labelling and benchmarking

Rationale

The main purpose of this proposal is to verify if the requirements specified with respect to the LENI/AECI values as proposed in sections 7.3.1, 7.3.2 or 7.3.4 are satisfied in practice. One aspect of this is to ensure that an appropriate and transparent design documentation process be put in place. Labelling of lighting systems is also discussed in section 7.3.11.

The photometry files of each of the luminaire types used is an essential element to enable calculation of the lighting installation performance according to EN 13201-5 or EN 13201-5, as discussed in that standard's installation requirements. The photometry file can be easily measured and verified. Also luminaires are an integral part of an installation and their parameters that influence the installation performance can be easily verified. In the case of a subsequent failure this documentation is also useful to facilitate repair with equivalent luminaires. Luminaires are sold with various photometries in the same housing and in the event of repair this is important information to have available.

It is also important to know the assumption behind the LENI or AECI&PDI calculation. This can help to monitor the proper function of the system, eventually optimize and correct control system settings or even to upgrade or modify it on the long term (i.e. so-called continuous commissioning).

For LENI in indoor systems this means that the detailed calculation parameters(Fd, Fo, Fc) and assumptions per area are reported as proposed in prEN15193:2016. For AECI in road lighting it are mainly the CL parameter and the dimming scenario(e.g.: tfull, tred, kred). In indoor it is also useful documentation to know the technical details contributing the lighting installation efficacy as illustrated in
Figure 1-3 or alternatively the so-called expenditure factors that are elaborared in draft standard prEN 15193:2016. They could be useful for continuous commissioning to evaluate upgrades of parts of the system during the course of the long life time of such systems, for example when more efficient luminaires or new control systems become available.

Proposal
The tenderer shall provide the following information for new or renovated lighting systems:

- a calculation of PDI, AECI or LENI (as appropriate) shall be provided by the tenderer and shall be made according to EN 13201-5:2016 or EN 15193. Additionally, the photometry file of the luminaires shall be provided. Where dimming is applied the dimming assumptions shall be described
- a statement that the minimum criteria for PDI, AECI or LENI are met taking into account the applicable policy requirements (see sections 7.3.1, 7.3.2 or 7.3.4)
- disassembly instructions for luminaires
- instructions on how to replace lamps, and which lamps can be used in the luminaires without decreasing the stated energy efficiency
- instructions on how to operate and maintain lighting controls
- for daylight linked controls, instructions on how to recalibrate and adjust them
- for time switches, instructions on how to adjust the switch off times, and advice on how best to do this to meet visual needs without excessive increase in energy consumption
- For indoor lighting a design file with per task area the assumed lighting design parameters used in EN 15193 calculations, e.g.: average illuminance, luminaire efficacy, type of control system, maintenance plan(e.g. cleaning cycles)/maintenance factor (F_M) and key parameters for the calculation (Fd, Fc, Fo, η_L, F_U(where applicable))
- For road lighting a design fill with per road segment with the key parameters (ηls, F_M, F_U, F_{CLO}, CL, kred, tfull, tred) as defined in EN 13201-5:2016

Pros and cons of proposed measure
Measures to encourage the provision of good quality information and documentation with respect to the energy performance of lighting systems will clarify the value proposition of efficient lighting systems to service procurers and hence can be a stimulus for demand of more efficient systems. To be beneficial these tendering processes need to be supported by relieable evidence of the performance of the lighting system. This information also facilitates future repair of the lighting system in the event of failure.

The cons concern the practical constraints on how rapidly such service requirements can be rolled out and these are tied to the choice of delivery instrument (discussed in the next section) and the maturity of the supply chain. In order to be effective it is also recommended that a good sent of bench mark values are developed for a representative set of applications. Most likely such bench mark values should be regularly updated due to the continuous improvements in the lighting market and when new applications are entering the market.

Suitability of policy instruments to implement proposed policy measure

Generic Ecodesign requirements are well suited to mandating information and documentation requirements. Other routes include national ordinances or building code specifications.

Timing
The timing of the roll out of this policy are the same as those specified for section 7.3.4 as applying to the imposition of Ecodesign requirements.

7.3.6 A proposal for information and documentation requirements at commissioning of new installations

Rationale
In order to obtain in real life LENI/AECI values in line with the design LENI/AECI values it is important that luminaires are installed in a manner that respects the design specifications and the calculations behind them, that control systems are installed and programmed accordingly and that the relevant surface reflections are in line with the assumptions. If the system underperforms compared to the design there is an additional risk that users will override dimming system settings and that consumption in real life will be greater than the projected LENI or AECI values at the design stage[223]. Therefore there is a need to strengthen the commissioning process to increase the likelihood that the design LENI/AECI values are achived in practice[224].

Proposal
The proposal is that measures shall be implemented to ensure that lighting system tenderers ensure that the lighting equipment (including lamps, luminaires and lighting controls) is installed exactly as specified in the original design and that it operates as intended. The layout plan and parts list of installed lighting equipment with appended manufacturers' invoices or delivery notes, and confirmation that the equipment is as originally specified.

In the case of road lighting it is proposed that for a selected road segment the contractor shall select two or more lighting poles for which they shall supply a measurement certificate which certifies that this road segment is being operated in accordance with the EN 13201-2 road class. The AECI shall be for example measured over the period of one day.

For indoor lighting: for a selected area in the building a measurement certificate shall be supplied that certifies that this area segment is operational in a manner that is fully inaccordance with the requirements of the EN 12464 standard. The LENI shall be measured over the period of one week before the final commissioning and compared to the annual forecast LENI corrected using the monthly data of prEN15193:2016 Annex F.6.

Note that alternatives to these specific proposals could be further investigated and discussed with stakeholders, especially to simplify and reduce commissioning cost.

Pros and cons of proposed policy measure

[223] and which in the future could potentially be required to respect the policy provisions considered in sections 7.3.1,7.3.2 or 7.3.4,
[224] Note, the correct operation of the control systems can also have a strong impact on the forecast EN13201-1 AECI or EN 15193 LENI parameter [kWh/(m².y)], while metering can also be a useful practice to help identify the correct control system settings and to verify that the forecast LENI or AECI are attained.

Measures to encourage the provision of proof that the lighting system has been operated in line with the design specifications with respect to energy performance and quality will lower the risk of other policy measures (such as those specified in sections 7.3.1, 7.3.2 or 7.3.4) being ineffective. They will also oblige service specifiers/ designers and installers to be able to systematically deliver reliable lighting systems that perform as intended. In addition this will help demonstrate the value proposition of efficient lighting systems to service procurers and hence can be a stimulus for demand of more efficient systems.

The cons concern the practical constraints regarding how rapidly such service requirements can be rolled out and these are tied to the choice of delivery instrument (discussed in the next section) and the maturity of the supply chain. There is also an added cost of doing business associated with the time and expense it takes to conduct the commissioning exercise but this is hopefully recovered for the supplier through the extra fees that would apply and for the procurer/end-user by the avoided energy expenditure and reduced risk of return calls.

Suitability of policy instruments to implement proposed policy measure
The Ecodesign Directive is well suited to mandating information and documentation requirements. Other routes include national ordinances or building code specifications.

Timing
The timing of the roll out of this policy are the same as those specified for section 7.3.4 as applying to the imposition of Ecodesign requirements.

7.3.7 A proposal for complementary minimum performance requirements for luminaires and controls used within lighting systems

Rationale
Apart from the installation and information requirements in line with EN 13201-5 on AECI or EN 15193 on LENI as proposed in sections 7.3.5 and 7.3.6 the imposition of minimum luminaire energy performance requirements for labelled compatible luminaires could also be considered. Note, there is a proposal concerning the scope of luminaires in section 7.1.4. Allthough this is a redundant requirement with LENI or AECI the main rationale could be that this requirement is more easy to verify/measure and it could help designers in preselecting luminaires inspite of the fact that other non-labelled luminaires would remain available on the market for other applications. In this context be aware that the parallel light source review study lot 8/9/19 is completed[225] (summary in Annex N) and that consequently the review of Ecodesign Regulation is already ongoing. So far the review focused on 'horizontal' lighting product requirements which are mostly irrespective of their intended applications. What we are discussing hereafter is to consider in the future also a complementary track with additional more ambitious requirements for products declared compatible with certain types of lighting system applications but as a consequence not for other types of applications. Therefore this will not have any impact on the total range of lighting products that remain available on the market but will provide a confirmation that the lighting systems within their application scope are constructed with efficient light sources only.

Proposals:

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

Minimum requirements can be considered for:

- Luminaire efficacy related to appications in EN 12464-1 and EN 13201.
- Minimum life time and lumen maintenance requirements.
- Minimum provision of smart control interface to enable light output control, because smart controls resulted in Task 4 into savings for all reference applications and this function can be easily verified;
- control interface based on an open standard or specification, this can positively impact the economic life time of an installation and avoid long term problems related to vendor lock-in, especially when the manufacturer fails during the life time of the installation;
- Design for retrofitting, especially in case of use of low efficacy components;

Pros and cons of proposed policy measure:
Although it could be argued that were the policy proposals specified in sections 7.3.6 and 7.3.6 to be adopted that minimum luminaire energy performance requirements would be redundant, there are several other reasons why they should be considered:
They make it more likely that the reasonable efficiency lighting systems will be installed by removing low efficiency luminaires from the market – such limits would remove the temptation for lighting specifiers to choose low efficiency luminaires by removing the option, provide a backstop in the event of poor or imperfect implementation of the other policy proposals, make it more likely that luminaire suppliers products are consistent with the lighting system needs, and simplify market surveillance. In addition, were there to be any phasing of the introduction of the measures specified in sections 7.3.6 and 7.3.6 it would provide energy savings for systems that were not yet covered by those measures (including, for example, non-roadway related outdoor lighting).

The downside is that this would be an additional regulation; however, this is not double regulation as the luminaire requirements would impose obligations on the luminaire supplier whereas the measures addressing the system as a whole (sections 7.3.6 and 7.3.6) apply to the system specifier and installer. Lastly, the specification of luminaire requirements could also ensure that appropriate information on luminaire performance is made available to lighting specifiers/designers and installers.

Suitability of policy instruments to implement proposed policy measure
Specific Ecodesign requirements are well suited to mandating luminaire energy performance limits while Ecodesign can also be used to specify information and documentation requirements.

Timing
The timing of the roll out of this policy are the same as those specified for section 7.3.4 as applying to the imposition of Ecodesign requirements.

7.3.8 A proposal for minimum energy-related performance requirements for building or road construction and lay out to be used in lighting systems

Rationale
The building construction and lay out can have a strong impact on lighting system performance especially with respect to the impact of daylight. For road class M in EN 13201-2:2016 also the surface reflection has a large impact on the road luminance. Therefore setting minimum requirements on these aspects can also contribute to lighting system energy savings. In the case of increased daylight within buildings it may also contribute to user productivity and health benefits.

Proposal
In buildings, minimum daylight provisions could be established as follows:

- by making use of the draft European standard prEN 17037:2016 under preparation that describes minimum daylight requirements. This standard encourages building designers to assess and ensure successfully daylit spaces. Hence compliance to minimum levels contained in this standard could be made a mandatory requirement for certain types of buildings
- establishing requirement to install rooflights wherever viable.

For roadways, minimum road reflectivity provisions could be specified e.g. via:

- establishing requirement for minimum road reflection coefficients to be used, see CIE Publication No 66 (e.g. the most reflecting classes in CIE stardards are: C1, R1, N1).

Pros and cons of proposed policy measure
The pros are the encouragement such measures would make to energy savings and coasian benefits such as productivity, desirability of the building stock and health. The cons are the need to further clarify the range of trade offs and viability of specific prospective measures to ensure if they are actionable and bring clear net benefits. Another disadavantage could be that the architect would feel limited in their freedom of building design and they could also suffer from additional administrative cost to verify design their compliance with the proposed standards.

Suitability of policy instruments to implement the proposed policy measure
Measures to promote the use of daylight within buildings are well suited to specifications within building codes and could thus be promoted by amendment to the EPBD; however, this is not a straightforward topic as there can be a trade off between day light provision, heat losses and solar gains that requires a balanced approach. The initiation of work aimed at clarifying these issues with a mind to informing potential future building code requirements could be a logical first step to establishing a consistent EU-level approach to this issue.

Timing
A study could be launched and concluded within 2 years with a mind to framing a set of EU policy guidelines that could be integrated within MS building codes within 4 years.

7.3.9 A proposal to encourage monitoring of installations after putting into service

Rationale
The correct operation of the control systems has a strong impact on the actual EN13201-1 AECI or EN 15193 LENI performace [kWh/(m².y)], and thus the purpose of this policy is to encourage correct operation via lighting system monitoring and feedback that can identify deficiencies and support corrective measures when needed. Metering of the LENI or EACI value can strongly assist optimised operation and trouble shooting as well as clearly demonstrate the benefits from the adoption of efficient lighting solutions. Metering is also useful to ensure the correct control system settings are used and therefore to obtain the full economic benefits from smart controls as explained in Chapter 4. Please note that prEN15193-1:2016 also contains a LENI measurement method.

Proposal

It is proposed that the Commission should conduct analysis with the aim of establishing for which lighting systems it would be cost-effective for regulations to be put in place that require monitoring of the energy performance and related parameters of the lighting system. Once such work has been done for the lighting systems for which it is merited policies shall be promoted that encourage/require a monitoring system to be put in place to determine LENI & AECI values for each control zone in line with EN 15193 or EN 13201-5. The policy measures shall require tenderers to provide submeters for each control zone and to at least display the measured and forecast values. In addition to the LENI & AECI the lowest and highest power consumption values shall be monitored and displayed on at least a monthly basis for each control zone.

Pros and cons of proposed policy measure
The policy will only be applied to lighting systems for which there is a clear net benefit, *to be analysed in a full study including Task 6*. It should be noted that the cost of sub-metering has declined dramatically in recent years and that it is more more practical to implement than was previously the case. The aim of the proposed study is to delineate where the benefit-cost ratios become favourable and hence to determine under which circumstances the policy should be applied; nonetheless, a priori the provision of such information is not expensive and is highly informative. It is also likely to be consistent with future developments in the EPBD, with respect to smart readiness.

Suitability of policy instruments to implement the proposed policy measure
Requirements with respect to the metering of lighting systems could be introduced via national building codes, via ordinances or even in the future via revision of the EPBD. In the absence of mandatory requirements good practice guides and incentives could be used to encourage and promote such measures.

Timing
A study could be conducted and completed within 2 years and associated policy instruments rolled out within 1-4 years from that time.
The policy will only be applied to lighting systems for which there is a clear net benefit, *to be analysed in a full study including Task 6*.

7.3.10 A proposal for monitoring & benchmarking of existing installations

Rationale
Due to the long technical and economic life time of existing installations it can be a long time before any lighting system renovation takes place, e.g. 20 to 30 years (see 3.4.1). As a consequence it can take a long time before the full potential impact identified in Chapter 4 for improved lighting designs is realised. Measures which encourage monitoring and benchmarking of existing installations can motivate owners to renovate their installation more rapidly than would otherwise be the case through the identification of impressive cost-effective savings potentials.

Proposal
For outdoor lighting:
The installed power per km(P) shall be measured or calculated from the lamp wattage and pole distance. Note that for road lighting such measurement data should be available for billing and this is not an extra cost.

The benchmark can be based on a check of the installed power per km (P) which can be compared with the outcome of a given formula that provides a reference state of art power consumption (Pref) for an LED road lighting solution (Q1/2016), therefore based on data from this study:

For road widths (RW) up to 10 m:
Power per km [kW/km] could be compared with Pref [kW/km] = 0.161 x E,m[lx]
For larger road widths (RW), i.e. >10 m:
Power per km [kW/km] should be compared with Pref [kW/km] = 0.161 x E,m[lx] x RW/10

Note that with appropriate software the client or public authority in this case could be advised on pay back time for renovation projects.

For indoor lighting:
The LENI values shall be measured preferentially disaggregated per task area and/or control zone, see prEN15193-1:2016. Bechmark LENI values could be elaborated according to the state of art in public data bases to provide end users with insight on what annual savings could be further expected. More work could be done for smart monitoring taking into account the lighting system decomposition as illustrated in Figure 1-3, it could help to provide the client with more insight where further optimisation should come from (luminaire efficacy?, installation efficacy?, daylight contribution?, occupancy control?, etc.).

Pros and cons of proposed policy measure
The policy will only be applied to lighting systems for which there is a clear net benefit, *to be analysed in a full study including Task 6.* It should be noted that the cost of sub-metering has declined dramatically in recent years and that it is more more practical to implement than was previously the case. The aim of the proposed study is to delineate where the benefit-cost ratios become favourable and hence to determine under which circumstances the policy should be applied; nonetheless, a priori the provision of such information is not expensive and is highly informative. It is also likely to be consistent with future developments in the EPBD, with respect to smart readiness.

Suitability of policy instruments to implement the proposed policy measure
Measures to encourage the auditing and benchmarking of lighting systems are compatible with the spirit of the EED Article 8 on auditing, albeit they are not directly or explicitly included in this. Member States could be encouraged to introduce to promote and support the adoption of lighting systems audits and benchmarking, which in turn could be linked to the sub-metering proposal of section 7.3.4. A mixture of information, incentives or regulations could be envisaged to do this, although, in most instances the former two cases would be most appropriate. The revision of the EPBD could provide an opportunity to encourage MS to develop such policies.

Timing
The policy will only be applied to lighting systems for which there is a clear net benefit, *to be analysed in a full study including Task 6.*
A study could be conducted and completed within 2 years and associated policy instruments rolled out within 1-4 years from that time. Also more precise methods for benchmarking and guidance for complementary software could be developed.

7.3.11A proposal for a lighting systems energy label

Rationale
Lighting system energy performance needs to be made visible to market actors to encourage the adoption of efficient designs and to facilitate other complementary

measures that promote the adoption of good design. Energy labelling at the system level will ensure all the aspects of system performance are captured and not just those that pertain to light sources, control gear and some luminaires.

Proposal
The proposal put forward by LightingEurope as discussed in section 7.2.3 describes the main characteristics of such a proposal but requires additional work to define the label class boundaries by application area. Some of those application areas are analysed in this study but others are not and hence more work is needed, via a full preparatory study to enable all the class boundaries by application area to be derived.

Other areas that will need attention are:

- the method used to calculate the lighting systems boundary and efficiency (notably should these be space function dependent or whole building level application dependent)
- whether a physical label is required or simply the conveyance of the energy efficiency class within the tendering and procurement process
- the choice of legal instrument used to implement the proposal

These issues are discussed below.

Pros and cons of proposed policy measure
The proposal covers the principal application areas and by being focused at the system level ensures all aspects of energy performance in the use phase are addressed. It proposes levels that are application dependent, which recognises the greater homogenity of needs expected as a function of the application type. However, the proposal specifies that classes should be defined at the broad application-type level whereas it could also be argued that label classes designed to apply at the space function level (e.g. corridors, office areas, meeting rooms, toilets etc.) might be just as appropriate. There is clearly a trade-off between the greater homogeneity of needs at the space function level compared to at the whole application type level, versus the desire to keep the labelling sufficiently simple as to be actionable, which would tend to favour labelling at the whole lighting project and hence application type level. In any case, further work is needed to resolve this issue and also to assemble the information necessary to define the label classes and this could be the subject of a full preparatory study.

The other area which would require additional consideration is the process for verifying performance and conducting market surveillance for such systems. The approach used hitherto for market surveillance of packaged products will not work in the case of non-packaged products which are installed as systems; however, the experience of performance declaration, verification and market surveillance processes that was used for the energy labelling of domestic heating and hot water systems is likely to be adaptable to the needs of lighting systems.

Lastly, it might be argued that non-residential lighting systems, which are the target of the LightingEurope labelling proposal, are B2B products and hence do not need an energy label as such. In fact the label need not be (and probably shouldn't be) a physical label applied to the product but rather could be a lighting system energy performance classification system, wherein lighting designs/specifications are obliged to indicate the energy label classification of the proposed design within a tendering process and lighting installers are obliged to indicate the label class attained by the design as installed (which should be the same as that proposed in the design/specification stage). Such information would greatly simplify communication of the energy performancer of the system during the procurement process and hence would reduce the need to which the procurer would need expertise to understand this aspect of the service being procured.

Suitability of policy instruments to implement the proposed policy measure
In principal the Energy Labelling Directive is the appropriate policy instrument through which energy labelling regulations can be developed. As mentioned previously it has already been used to set product system energy labels in the case of packages of domestic space and water heating equipment. Furthermore there is nothing in the Directive text that precludes the setting of product labelling requirements in an application specific context and thus the type of lighting system labelling proposed in the LightingEurope proposal would be legally actionable within the context of the present Directive. However, in principle it would also be possible to use the information requirement provisions of the Ecodesign Directive to require the provision of information on the energy efficiency class of a lighting system – especially if no physical label is envisaged.

Timing
It is likely that more work would be needed to develop a sufficiently comprehensive set of LENI limit values that are fully adapted to the array of application types found in European buildings. A similar process would need to be followed to derive AECI and PDI values for roadways. Thus the timing of any labelling scheme would need to respect this process. Assuming such work could be concluded within 2 years (i.e. by the end of 2018) then either codes using LENI (or AECI/PDI) could be adopted within a year of that or a new Energy Labelling regulation for lighting systems issued within a year (i.e by the end of 2019). An Energy Labelling regulation would typically give market actors at least a year before they would have to comply with the requirements whereas building codes would tend to be immediate. Either way LENI limits could be in place for indoor lighting by the end of 2020 (and a similar schedule for roadway lighting). These would then require regular review, thus it is conceivable that further revised tiers could come into force in say 2025 and 2030. A challenge for this is that the available solutions on the market are still improving, see Chapter 4 on BNAT, and that such limits and/or benchmarks will benefit from a continuous update. Therefore the establishment of a centralised database with updated benchmarks for some reference designs could be useful such as the 'Lighting Facts Database' in in the US for LED luminaires[226].

7.3.12 Summary of potential research projects that can support previously discussed policy measures

In summart the following research could support the introduction and impact of previously discussed policy measures:

- For indoor lighting the calculated impact from daylighting controls and occupancy depends on the data included in standard EN 15193, e.g. factors Fd and Fo. Obvioulsly collecting and processing more data can increase the accuracy of the calculated LENI values. Therefore increased monitoring and sharing of benchmark data as disussed in section 7.3.10 will be useful and software platforms can be developed for that.
- The impact of controls in indoor lighting was calculated on what is currently modelled within prEN 15193:2016 but this did not cover all BNAT discussed in chapter 4 section 4.1.2, i.e. so-called holstic control systems with user feedback and human centric lighting.

[226] http://energy.gov/eere/ssl/led-lighting-facts

7.4 Scenario analysis methodology

Objective:

This section describes a set of policy scenarios and explains how they were analysed. It entails setting up a stock-model, running from 1990-2030 (but also to 2050) which is consistent with the MEErP and using this to calculate a baseline scenario ('BaU', 'Base Case') concerning the use of resources and emissions (in physical units). It should then go on to calculate scenarios for the policy options identified in the previous section 7.3. Many of the proposed policy options did not involve the setting of strict minimum performance requirements and the assumed positive impact is thus a less directly determinable consequence of the proposed methods and practices. Therefore this study will calculate the baseline (BAU) scenario and some most optimistic best case scenarios related to the improvement options of task 4. These best case scenarios are intented to be indicative of what is achievable with the proposed policy measures were they to deliver their maximum impact. Also introducing lighting design policy requirements could in theory induce a rebound effect when they are related to minimum illumination requirements according to EN 12464-1 for indoor and EN 13201-2 for road lighting, meaning that user would install higher levels as they would do intuitively without measurable specifictions and therefore consume more. In practice we think that the impact of this effect in the scenarios should be negligible because the base case in Task 4 are already quite optimised and had low LENI & AECI values when they were compared to stock data in Tasks 1&2.

7.4.1 Introduction to Scenario Analysis

According to the MEErP[227], scenario analysis typically involves the creation of a stock model for the product type being considered in accordance with the following:

a) Create a generic stock model for the 1990-2030 baseline (Business-as-Usual, 'BAU') specifying sales, stock, performance (e.g. lumenoutput, operating hours, product life), significant energy and environmental impacts (e.g. in kWh, kg CO_2 eq.);
b) Perform a scenario (ECO) analysis for the above parameters, in terms of absolute, relative (versus BAU) and accumulative impacts (versus BAU).

However, compared to other products that have been the subject of Ecodesign preparatory studies, a 'lighting system' has different characteristics that are difficult to capture in a traditional stock model, while reliable sales data for 'lighting systems' are not available (see Task 2). In addition, the energy consumption of lighting systems is closely related to the energy consumption by light sources, which have been separately examined in the ENER Lot 8/9/19 preparatory study that was concluded in October 2015[228].

Consequently, no separate stock model has been created for 'lighting systems', and the scenario analysis is performed using an extension to the 'Model for European Light Sources Analysis' (MELISA) that was used in the Lot 8/9/19 study.

MELISA was specifically developed on request of the European Commission with the aim to harmonise the data for the two related preparatory studies on lighting, i.e. 'lighting systems' and 'light sources'. A description of the October 2015 version of

[227] MEErP 2011, Methodology for Ecodesign of Energy-related Products, part 1: Methods and part 2: Environmental policies and data, René Kemna (VHK) November 28th 2011; in particular see Part 1, chapter 7.

[228] See: http://ecodesign-lightsources.eu

MELISA can be found in the Task 7 report of the Light Sources study[229]. During the 2016 Impact Assessment for light sources MELISA was changed, to incorporate new input supplied by the industry association LightingEurope[230]. The most recent available version of MELISA, dated July 2016, has been used in the present Lighting Systems study.

As anticipated in section 2.1, the MELISA scenarios developed for the light sources study are used as reference scenarios for the present lighting systems analysis. The additional effects of lighting system improvements are evaluated by means of two parameters which are the Flux Factor (F_{phi}) and the Hour Factor (F_{hour}).

By this approach double counting of energy savings obtained from increasing the light source efficacy are discriminated and excluded from the scenarios developed for this lighting system study.

The details of the methodology applied are explained in the following paragraphs.

7.4.2 Flux Factor and Hour Factor for reference cases

In Task 4 lighting system designs have been defined for several reference cases (indoor space types or outdoor road types). Typically, four design cases have been made for each indoor application reference case as follows:

- Base Case design: intended to represent the average current practice,
- Optimised design: improved layout of the luminaires in the space, and application of luminaires with higher light output efficacy, while maintaining the lighting requirements in the task areas. With respect to the base case, the optimised design leads to a lower total installed luminous flux (at light source level) in the space. The ratio of the installed flux of the optimised design and the installed flux of the base case design is defined as the Flux Factor (F_{phi}).
- Optimised design + Controls: in addition to the optimised design, sensors and controls are added to the system so that lights can be dimmed or switched off in function of daylight availability, room occupancy and/or lumen degradation with time. With respect to the base case design, the 'optimised design + controls' leads to lower annual full-power equivalent (fpe) operating hours. The ratio of the hours of the controlled design and the hours of the base case design is defined as the Hour Factor (F_{hour}).
- Optimised design + Controls + Surfaces: the difference with the preceding design is that room surface reflectance is also improved. This

[229] http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task7%20Final%2020151031.pdf, Annexes D, E and F.
[230] These changes mainly regard the lifetime, average luminous flux, power and efficacy of LFL and HID-lamps. The lifetime for LEDs substituting LFL and HID was also increased. To enable lifetime to be variable with the years, a lifetime distribution was introduced for LFL T8t, LFL T5, HPS, MH and LEDs substituting these lamps. The main effect of these changes, with respect to results reported in Task 7 of the Light Sources study, was that energy savings in 2020 and 2025 slightly decreased while savings in 2030 increased.

enables a better use of available daylight and a further reduction in fpe operating hours, i.e. a lower Hour Factor.

For outdoor road lighting cases, the first three designs cases described above are developed and used in a similar manner.

Table 7-5 gives a survey of the Flux Factors F_{phi} and Hour Factors F_{hour} that have been derived from the data for reference case designs presented in Task 4. The reference cases in the top part of the table are for indoor lighting and mainly related to the use of fluorescent lamps. Those in the bottom part are for outdoor (road) lighting or for indoor lighting of large manufacturing halls, and mainly related to the application of high-intensity discharge lamps.

Taking cellular offices with ceiling mounted luminaires as an example, F_{phi} =0.67 means that in an optimised design the total luminous flux of the installed light sources can be reduced to 67% of the flux in the base case design while maintaining the required light level in the task areas. F_{hour}=0.48 means that adding lighting controls can reduce the full-power equivalent annual operating hours to 48% of those for the system without such controls.

Table 7-5 Flux Factors and Hour Factors for the reference lighting cases, as derived from data presented in Task 4.

	optimised design	optimised design & controls	optimised design & controls & surfaces
FL-related (Indoor) applications	Flux Factor	Hour Factor 1	Hour Factor 2
office, cellular, ceiling mounted	0.67	0.48	0.29
office, cellular, suspended	0.78	0.44	0.25
office, open, ceiling mounted	0.68	0.65	0.46
office, open, suspended	0.78	0.67	0.47
corridor etc.	0.67	0.91	0.65
large DIY	0.98	0.83	0.53
supermarket	1.00	0.90	0.67
industry, workshops	0.50	0.65	0.59
warehouse, general	0.88	0.58	0.25
warehouse, racks	1.00	0.82	0.49
HID-related (Outdoor&Indoor) applications			
Motorways	0.52	0.65	
main or national roads	0.67	0.65	
secondary or regional, rural or mixed residential	0.52	0.75	
secondary or regional, mixed conflict	0.55	0.75	
other roads, mixed traffic	0.50	0.65	
other roads, residential streets P4	0.61	0.85	
other roads, residential streets M5	0.70	0.85	

industry, large manufacturing halls	0.60	0.88

7.4.3 Energy shares for reference cases and Weighted average Factors

It is clear from *Table 7-5* that factors F_{phi} and F_{hour} differ between the reference cases. These individual factors cannot be directly used in MELISA because that model is not subdivided in room types or road types. Instead, the data in MELISA are defined per lighting technology, e.g. LFL-, HID- and CFLni-application groups. Consequently, for use of the factors in MELISA we need to compute average values for F_{phi} and F_{hour} for FL-applications[231] and HID-applications.
Considering that the various reference cases do not have identical energy impacts, it would not be correct to take the arithmetic average: an energy-weighted average of F_{phi} and F_{hour} for FL- and HID-applications is required. Therefore the relative energy-impacts of the various reference cases are first estimated below.

Indoor reference cases (related to fluorescent lamps):
For indoor reference cases a LENI in kWh/m^2/a has been defined for the base design in Task 4. Multiplying these values by the EU-28 total areas associated to each reference case[232] (from Task 2) enables an estimate for the annual electricity consumption in TWh/a to be obtained, as shown in *Table 7-6*.

The total electricity consumption for all indoor reference cases is 110 TWh/a (including 8 TWh for large manufacturing halls related to HID-lamps). The comparable value in MELISA (2015)[233] is 168 TWh/a (of which 153 if for LFL, 7 CFLni, and 8 for HID-lamps). This implies that the indoor reference cases (excluding the 8 TWh/a of the HIDs for manufacturing halls) cover (110-8)/(168-8)=63% of the total electricity consumption for indoor non-residential fluorescent lighting.

The electricity shares for the individual reference cases shown in the last column of *Table 7-6* and in *Figure 7-2* are the weighting factors necessary to determine the average F_{phi} and F_{hour} for application to the LFL- and CFLni application groups in MELISA.

Outdoor and Manufacturing Halls reference cases (related to HID-lamps):
For road lighting reference cases the electricity consumption has been derived from the 2015 stock model presented in Task 2, multiplying the stock by the average power (dependent on road type) and by the annual operating hours (4000 h/a assumed for all types). The result is shown in *Table 7-7* and *Figure 7-3*.

The total electricity consumption for all HID-related reference cases (outdoor roads and indoor manufacturing halls) is 42.2 TWh/a. The comparable value in MELISA (2015) is 68.9 TWh/a (all HID-lamps, incl. control gear). This implies that the HID-related reference cases cover 61% of the total HID-related electricity consumption modelled in MELISA. This sounds reasonable because HID lamps are also used in other

[231] A single average value is used for FL-applications and this value is applied to both LFL- and CFLni-applications in MELISA. This simplified approach has been chosen considering that the influence of CFLni in the systems' analyses is very small.
[232] On several occasions there are two reference cases associated to a single estimated area. In these cases half of the total area has been assigned to each reference case. E.g. 'cellular offices' with total EU-28 area of 1185 Mm^2, 593 Mm^2 assigned to both 'ceiling mounted' and 'suspended'.
[233] MELISA values include control gear energy, because LENI values also include the control gear.

non-residential indoor and outdoor applications that were left out of the scope of this system study, e.g.: sport fields lighting, industrial outdoor work places(EN 12464-2), architectural or monument lighting, horticulture lighting, accent lighting in shops, theatres, etc..

The electricity shares for the individual reference cases shown in the last column of *Table 7-7* are the weighting factors necessary to determine the average F_{phi} and F_{hour} for application to the HID-application group in MELISA.

Table 7-6 Electricity consumption for indoor lighting reference cases, and weighting factors for averaging F_{phi} and F_{hour} for FL-application groups of MELISA.*

Indoor reference case	LENI kWh/m²/a	Total area M m²	electricity	
			TWh/a	Share°
cellular offices, ceiling mounted (incl. general small offices)	19.0	593	11.3	7.0%
cellular offices, suspended (incl. general small offices)	19.1	593	11.3	7.1%
open offices, ceiling mounted	22.1	305	6.7	4.2%
open offices, suspended	17.7	305	5.4	3.4%
corridors (incl. all circulation areas, and toilets etc.)	11.3	2449	27.6	17.3%
shops > 30 m², large (DIY 8000 m²)	46.9	201	9.4	5.9%
shops > 30 m², medium (supermarket 1200 m²)	57.3	201	11.5	7.2%
manufacturing, large halls (6272 m²)	11.0	738	8.1	HID
manufacturing, small workshops (392 m²)	14.9	738	11.0	6.9%
storeroom/warehouse, general (7000 m²)	11.3	387	4.4	2.7%
storeroom/warehouse, racks (600 m²)	7.0	387	2.7	1.7%
all studied reference cases for FL, average or total	**15.9**	**6895**	**110⁺**	**63.4%**
not covered by studied reference cases		4878	59	36.6%
total, all non-residential buildings/room types		**11773**	**168⁺⁺**	**100.0%**

* Electricity consumption values include control gear energy, but not the energy consumed by controls and standby
\+ Including 8.1 TWh for HID lamps in large manufacturing halls
++ Including 153 TWh for LFL, 7 TWh for CFLni and 8.1 for HID in large manufacturing halls
◦ Share in total for LFL and CFLni of 160 TWh/a (168-8.1 of HID in manufacturing halls).

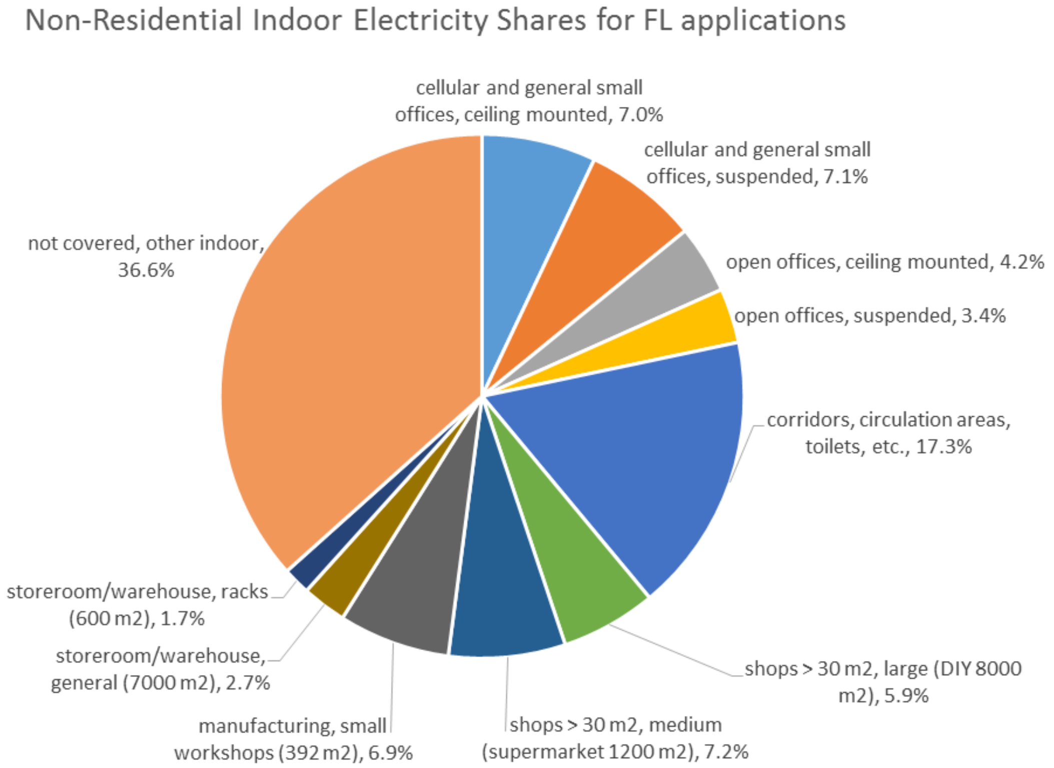


Figure 7-2 Non-Residential, Indoor, Electricity shares for fluorescent lamp reference cases (weighting factors for averaging of F_{phi} and F_{hour} for FL-applications).

Table 7-7 Electricity consumption for road lighting reference cases (for 4000 h/a) and other HID-reference cases, and weighting factors for averaging F_{phi} and F_{hour} for HID-application group of MELISA.*

Outdoor or Indoor reference case	Stock estimate 2015^{+}	Average power (W)	electricity	
			TWh/a	share
Motorways	175,855	800	0.6	0.8%
Main or National roads	782,207	300	0.9	1.4%
Secondary or regional roads: rural roads or mixed with residential	8,568,145	200	6.9	9.9%
Secondary or regional roads: mixed conflict	745,056	600	1.8	2.6%
Other roads: mixed traffic	21,605,268	150	13.0	18.8%
Other roads: residential streets P4	16,203,268	80	5.2	7.5%
Other roads: residential streets M5	16,203,951	90	5.8	8.5%
Subtotal road lighting	**64,284,433**		**34.1**	**49.5%**
Indoor lighting of large manufacturing halls			8.1	11.8%
all studied reference cases for HID			**42.2**	**61.3%**
estimated outdoor HID not covered by reference cases			9.3	13.5%

estimated indoor HID not covered by reference cases[234]			17.4	25.3%
total, all non-residential HID-lighting			**68.9**	**100.0%**

* Electricity consumption values include control gear energy, but not energy for controls and standby
+ Expressed in number of poles.

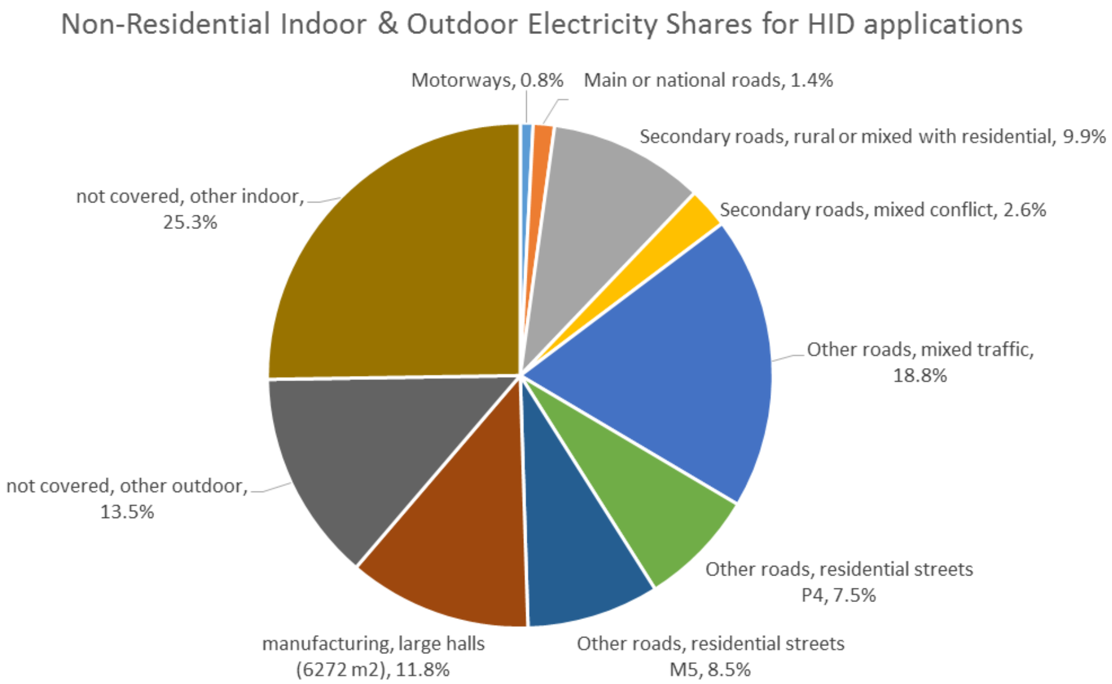


Figure 7-3 Non-Residential, Outdoor Roads and Indoor Manufacturing Halls, Electricity shares for HID-related reference cases (weighting factors for averaging of F_{phi} and F_{hour} for HID-applications).

Sales-average factors F_{phi} and F_{hour} for LFL- and CFLni-application groups:
For indoor reference cases related to fluorescent lamps, sales-averages for the factors F_{phi} and F_{hour} can now be computed using the weighting factors of *Table 7-6*.
As shown in *Table 7-8*, taking into account only the studied cases, the average Flux Factor = 0.75 and the average Hour Factor = 0.73. If surface reflections are also improved, the Hour Factor further reduces to 0.51.

Using these factors in MELISA would imply the assumption that the same factors apply to all non-residential FL-applications, including those that have not been studied. If, conservatively, it is assumed that no lighting system improvements will occur for cases that have not been studied, i.e. $F_{phi}=F_{hour}=1$ for non-studied cases, the overall average Flux Factor = 0.84 and Hour Factor = 0.83 (or 0.69 for improved surface reflectance).

Table 7-8 Energy-weighted sales-average F_{phi} and F_{hour} for LFL- and CFLni-application groups of MELISA.

[234] Obtained by calculating lamp consumption for road lighting in with Task 2 market data compared to total HID sales data from the light source study

Reference cases using fluorescent lamps	FL electricity share	optimised design	optimised design & controls	optimised design & controls & surfaces
	weight factor	flux factor	hour factor 1	hour factor 2
office, cellular, ceiling mounted	7.0%	0.67	0.48	0.29
office, cellular, suspended	7.1%	0.78	0.44	0.25
office, open, ceiling mounted	4.2%	0.68	0.65	0.46
office, open, suspended	3.4%	0.78	0.67	0.47
corridor etc.	17.3%	0.67	0.91	0.65
large DIY	5.9%	0.98	0.83	0.53
Supermarket	7.2%	1.00	0.90	0.67
industry, large halls (see HID)				
industry, workshops	6.9%	0.50	0.65	0.59
warehouse, general	2.7%	0.88	0.58	0.25
warehouse, racks	1.7%	1.00	0.82	0.49
not covered by reference cases	36.6%	1	1	1
weighted average for studied cases		**0.75**	**0.73**	**0.51**
weighted average when assuming factor 1 (no improvements) for non-studied cases		**0.84**	**0.83**	**0.69**

Sales-average factors F_{phi} and F_{hour} for HID-application group;
For reference cases related to HID-lamps (roads, manufacturing halls), sales-averages for the factors F_{phi} and F_{hour} can be computed using the weighting factors of *Table 7-7*. As shown in Table 7-9, taking into account only the studied cases, the average Flux Factor = 0.57 and the average Hour Factor = 0.77.
Using these factors in MELISA would imply an assumption that the same factors apply to all non-residential HID-applications, including those that have not been studied. If, conservatively, it is assumed that no lighting system improvements will occur for cases that have not been studied, i.e. F_{phi}=F_{hour}=1 for non-studied cases, the overall average Flux Factor = 0.74 and Hour Factor = 0.86.

Table 7-9 Energy-weighted sales-average F_{phi} and F_{hour} for HID-application group in MELISA.

Reference cases using HID-lamps	HID electricity share	optimised design	optimised design & controls
	weight factor	flux factor	hour factor
Motorways	0.8%	0.52	0.65
main or national roads	1.4%	0.67	0.65
secondary or regional, rural or mixed residential	9.9%	0.52	0.75
secondary or regional, mixed conflict	2.6%	0.55	0.75
other roads, mixed traffic	18.8%	0.50	0.65
other roads, residential streets P4	7.5%	0.61	0.85
other roads, residential streets M5	8.5%	0.70	0.85
indoor: manufacturing halls	11.8%	0.60	0.88
outdoor not covered by reference	13.5%	1	1

cases			
indoor not covered by reference cases	25.3%	1	1
weighted average for studied cases		**0.57**	**0.77**
weighted average assuming factor 1 (no improvements) for non-studied cases		**0.74**	**0.86**

Stock-average factors F_{phi} and F_{hour}:
The factors derived in the previous paragraph are sales-averages, i.e. they are valid for new installed lighting systems in a given year after introduction of a policy measure. In the scenario analysis the factors have been introduced starting from year 2020. However, they do not apply instantaneously to the entire stock of non-residential light sources: for application in MELISA stock averages are needed.
To compute these averages, the Flux Factor and Hour Factor values before 2020 are assumed to be 1: the influence of lighting system design and control in the current situation is taken as a reference for the computation of savings in later years.
A typical example of the difference between a sales-average and a stock-average factor is shown in *Figure 7-4*.

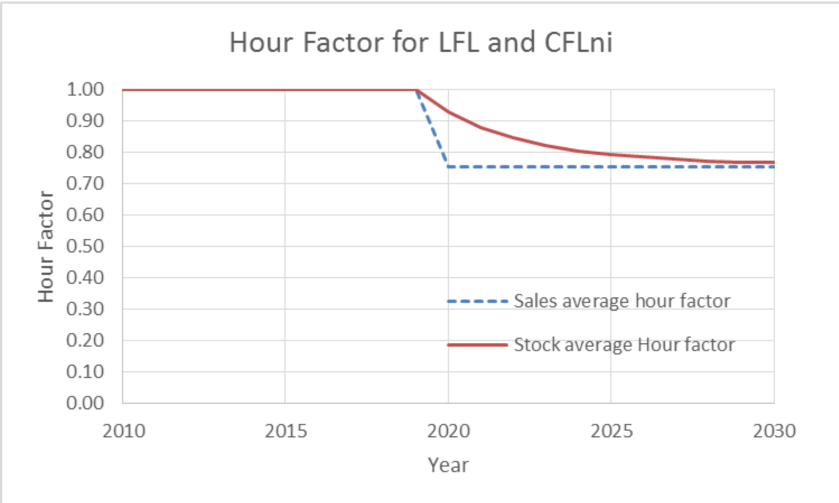


Figure 7-4 Example of the difference between sales-average and stock-average factor

7.4.4 Linking MELISA model sales to the introduction of lighting system improvements

Lighting system improvements would mainly be expected to be implemented when a new building or road is constructed or when an existing building or road is renovated. The speed of introduction of system improvements is then related to e.g. annual rate of increase in EU-28 building area and road length, maintenance plans for buildings and roads, lifetime of luminaires or of lighting installations, financial considerations (return on previous investments; estimated payback period for new investments in energy-efficient lighting systems; availability of money to invest), political decisions in municipalities.

MELISA is based on the sales and lifetimes of light sources, and the lighting system improvements (represented by the factors F_{phi} and F_{hour}) have to be linked in some way to those sales, which inevitably is a rough approximation of reality. This section explains what assumptions have been made.

With reference to *Figure 7-5*, according to MELISA there were 1900 mln LFL light sources installed in EU-28 in 2016 (stock). Each year a certain number of these lamps reach their end-of-life and have to be replaced. In addition the model assumes an annual growth of the stock leading to new sales. The two factors together lead to a certain quantity of potential LFL sales (269 mln in 2016). These potential sales lead to actual sales as follows:

- X% remain classical technology lamps (LFL substituting LFL; 249 mln in 2016),
- (100-X)% shift to LED lighting products, of which

  - Y% integrated LED luminaires (substituting LFL-luminaires; 7 mln in 2016).

  - (100-Y)% LED retrofit lamps (substituting LFL light sources; 13 mln in 2016)

The same principle is applied to CFLni and HID-lamps.

The shares of potential sales that are filled in by one of the three possibilities (classical, LED retrofit, LED luminaire) depend on scenario assumptions. The values X and Y differ from scenario to scenario and within each scenario they vary with the year. The BAU scenario for light sources already includes a shift in sales from classical light sources to LEDs according to the current trend and future expectations, decreasing the share X with the years. An ECO scenario will typically phase-out a part or all of the classical lamps and thus accelerates the shift to LED: the share X goes to zero for the phased-out classical lamp type and all associated sales shift to LED.

The division between LED retrofit lamps and integrated LED luminaires (share Y) also depends on the scenario and varies with the years. For classical light source types where LED retrofits are absent or scarce, such as CFLni, LFL T5 and HID-lamps, a high share of integrated LED luminaires is assumed (typically: Y=80% in 2016). Where LED retrofits are available, e.g. LFL T8, the share of integrated LED luminaires is taken lower (typically: Y=30% in 2016). In both cases the model anyway assumes a trend towards use of LED luminaires, i.e. the share Y increases with time.

For the analysis of the impacts of lighting system improvements, it has been assumed that, in a given year:

- No system improvements are applied to the part of the existing stock for which no new light sources are bought in that year,
- No system improvements are related to the sales of classical technology lamps: just replacing a lamp by one of the same type is not a likely occasion for the introduction of lighting system improvements,
- No system improvements are related to the sales of LED retrofit lamps. Essentially this is the same as the previous point, but using a light source with higher efficacy. As also stated before: the energy savings due to efficacy improvements of the light sources are already counted in the reference scenarios and are thus not counted again as systems' savings.

Consequently system improvements are assumed to be only related to the MELISA sales of light sources in integrated LED luminaires. If the buyer is anyway replacing all its existing luminaires, this is the most likely occasion to introduce system improvements.

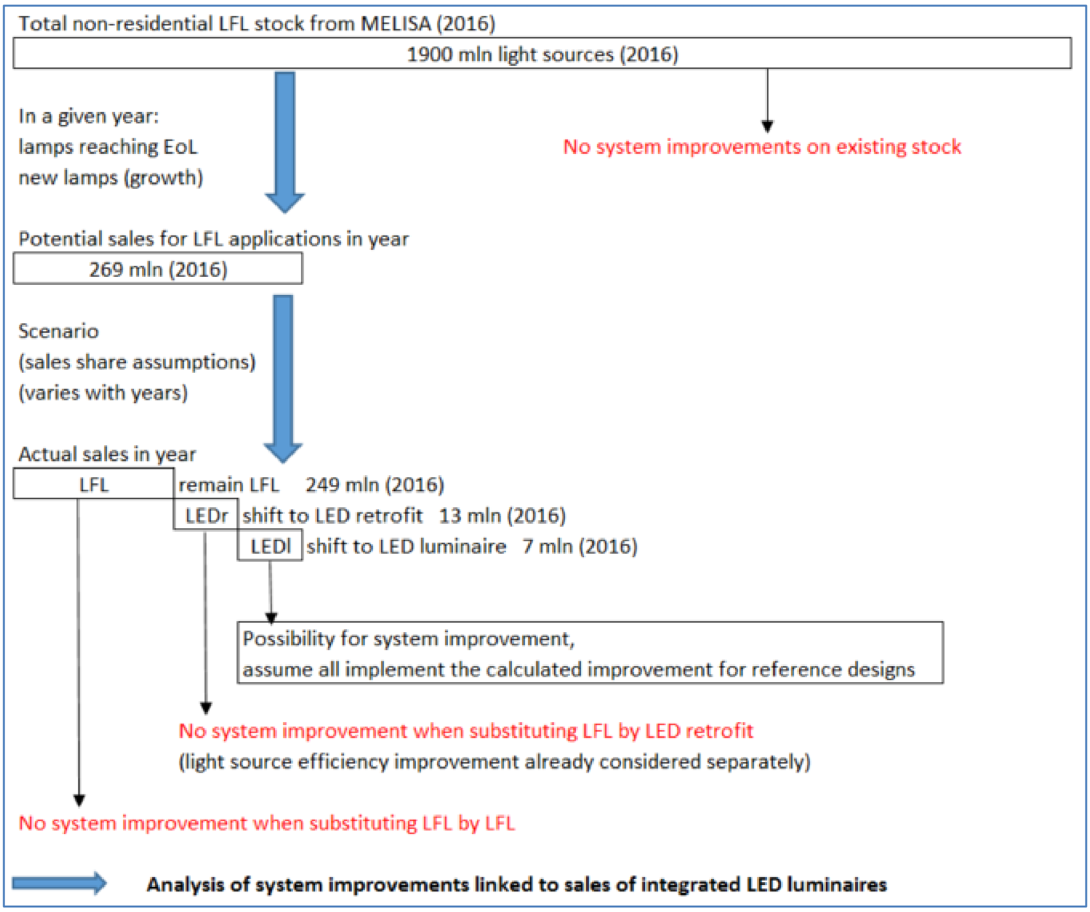


Figure 7-5 The introduction of lighting system improvements is linked to the MELISA sales of light sources inside integrated LED luminaires, i.e. to moments when users are substituting their classical technology luminaires.

7.4.5 Details on implementation of system improvements in the MELISA model

For a given light source efficacy[235], the electricity consumption is directly proportional to the installed luminous flux (of light sources) and to the annual full-power equivalent operating hours. Consequently, the electricity consumption after implementation of lighting system improvements (E_{after}) can be derived from the one before lighting system improvements (E_{before}) using:

$$\mathbf{E_{after} = E_{before} * F_{phi} * F_{hour}}$$

[235] I.e. the efficacy of LED lamps as defined in MELISA. This efficacy increases with the years and is higher for non-residential light sources than for residential light sources. The average efficacy of LED lighting products also depends on the introduction of energy-labelling improvements. For details see the Task 7 report of the Lot 8/9/19 light sources study.

F_{phi} and F_{hour} are the stock-average factors as derived in par. 7.4.3 .

E_{before} is taken as the electricity consumption (including control gear) of integrated LED luminaires (replacing LFL, CFLni or HID-luminaires) in a MELISA reference scenario (BAU- or ECO-scenario for light sources[236,237]). These scenarios already include a shift from classical lighting technologies to LED lighting products and consequently already take into account the energy savings due to improvements in light source efficacy.

Taking a MELISA scenario as reference, and applying the factors F_{phi} and F_{hour} to include effects of lighting system improvements, ensures compatibility between the Light Sources study and the Lighting Systems study and also avoids the risk of savings due to light source efficacy improvements being counted twice.

The reference scenarios are those defined in the Task 7 report of the Lot 8/9/19 light sources study[238]. In particular, savings due to improvements in lighting systems have been examined with respect to:

- Light source BAU-scenario (without energy label improvement)
- Light source ECO 80+120 scenario (without energy label improvement)
- Light source ECO 80+120+LBL scenario (with energy label improvement)

Energy savings due to system improvements are computed as $E_{before} - E_{after}$ (a positive number indicates a saving).

The additional control energy associated with lighting system improvements (in the option with additional use of controls) has not been taken into account: using currently available data (see Task 4) this additional energy is small (around 1.5-2.0% of light source energy), and well within error margins of the energy saving estimates.

Share of MELISA model electrical energy to which system improvements are applied:

[236] These reference scenarios intend to represent the current practice as regards the use and installation of (optimised) lighting systems. The BAU scenario for light sources includes a shift towards LED lighting products that is assumed to take place in absence of additional ecodesign regulations on light sources. The ECO-scenario for light sources accelerates this shift by phasing out some conventional lamp technologies by means of new ecodesign measures for light sources. The process of defining such new measures is still ongoing (August 2016).

[237] The first idea was to apply sales-average Fphi and Fhour directly to the sales average luminous fluxes and operating hours used in MELISA. For several reasons, this idea has been abandoned:

- Direct application of the Hour factor to the MELISA full-power equivalent (fpe) annual operating hours would lead to the reduction of these hours and consequently to a longer lifetime in years of the associated lamps (lifetime in years = lifetime in hours / annual fpe operating hours). This change in lifetime is doubtful and it would change all sales and stock figures. For the moment it has been preferred to assume that the lifetime in years does not change when introducing system improvements.
- Until now MELISA assumed that the operating hours declared for a given year would apply to the entire stock in that year, i.e. it was conceived as a user-parameter and not as a product-parameter. However, introducing system improvements, would result in some applications operating with the new lower hours, but others would continue to operate with the original hours, so a stock average calculation for hours would have to be added to the model and linked to the energy calculations. This would be possible, but for the moment has not been done.
- Applying the Flux factor directly to the sales average luminous flux of MELISA would not work properly. The mechanisms with which LEDs inherit the fluxes from the classical lamps that they replace, and the calculation of stock averages for the flux of LEDs, have become rather complex. The way it is done now would mean that the Flux Factor would be counted double (or multiple times) when LEDs start to substitute LEDs. This is not just a theoretical problem: after the introduction of the lifetime distribution also for LEDs, some LEDs reach EoL earlier than their average lifetime. In addition the lighting system analysis requires a model horizon beyond 2030 (up to 2050) to see its effects, and this increases the problem of LEDs substituting LEDs.

[238] http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task7%20Final%2020151031.pdf

The following data illustrate the electricity consumption of LED luminaires used in former LFL-, CFLni- and HID-applications, in relation to the total lighting electricity (22% in 2030, growing to 47-59% in 2040-2050), to the non-residential electricity (26% in 2030) and to the total electricity of LFL-, CFLni- and HID-applications (27% in 2030). These data are from the MELISA BAU scenario; the quantities are in TWh/a and include control gear energy. Energy for controls and standby is not included. Special purpose lamps are also excluded.

The electricity consumption of LED luminaires used in former LFL-, CFLni- and HID-applications is distinguished in blue italic text in the *Table 7-10*. The reference cases studied can be assumed to represent 61-63% of this energy. Consequently, if no system improvements are assumed for cases that have not been studied, the maximum possible energy savings would be around 62% of the blue values reported in the table, i.e. 38 TWh in 2030, 75 TWh in 2040 and 107 TWh in 2050.

Table 7-10 MELISA model electrical energy for integrated LED luminaires to which system improvements (represented by F_{phi} and F_{hour}) are applied (blue italic figures), in relation to other lighting electricity.

EU-28 ELECTRICITY in TWh/a from MELISA BAU scenario	**2010**	**2015**	**2020**	**2025**	**2030**	**2040**	**2050**
Residential (total)	94.5	82.1	48.1	35.7	33.2	32.3	33.7
NRES other than LFL, CFLni, HID	29.1	23.7	14.8	6.4	2.6	0.3	0.0
NRES LED replacing other	0.0	0.5	3.9	8.1	10.6	14.3	18.1
NRES, LFL, CFLni, HID	204.4	217.0	217.5	191.6	138.6	50.2	18.0
NRES, LED retrofit for LFL, CFLni, HID	0.0	3.2	10.5	19.1	28.0	38.5	47.9
NRES, LED luminaire in former LFL, CFLni, HID application	*0.0*	*8.2*	*19.2*	*35.7*	*61.6*	*121.1*	*172.8*
TOTAL	**328**	**335**	**314**	**297**	**275**	**257**	**291**
share of LED lum in total	0%	2%	6%	12%	22%	47%	59%
share of LED lum in NRES	0%	3%	7%	14%	26%	54%	67%
share of LED lum in LFL, CFLni, HID-apps	0%	4%	8%	14%	27%	58%	72%

NRES = Non-Residential;   lum = luminaire

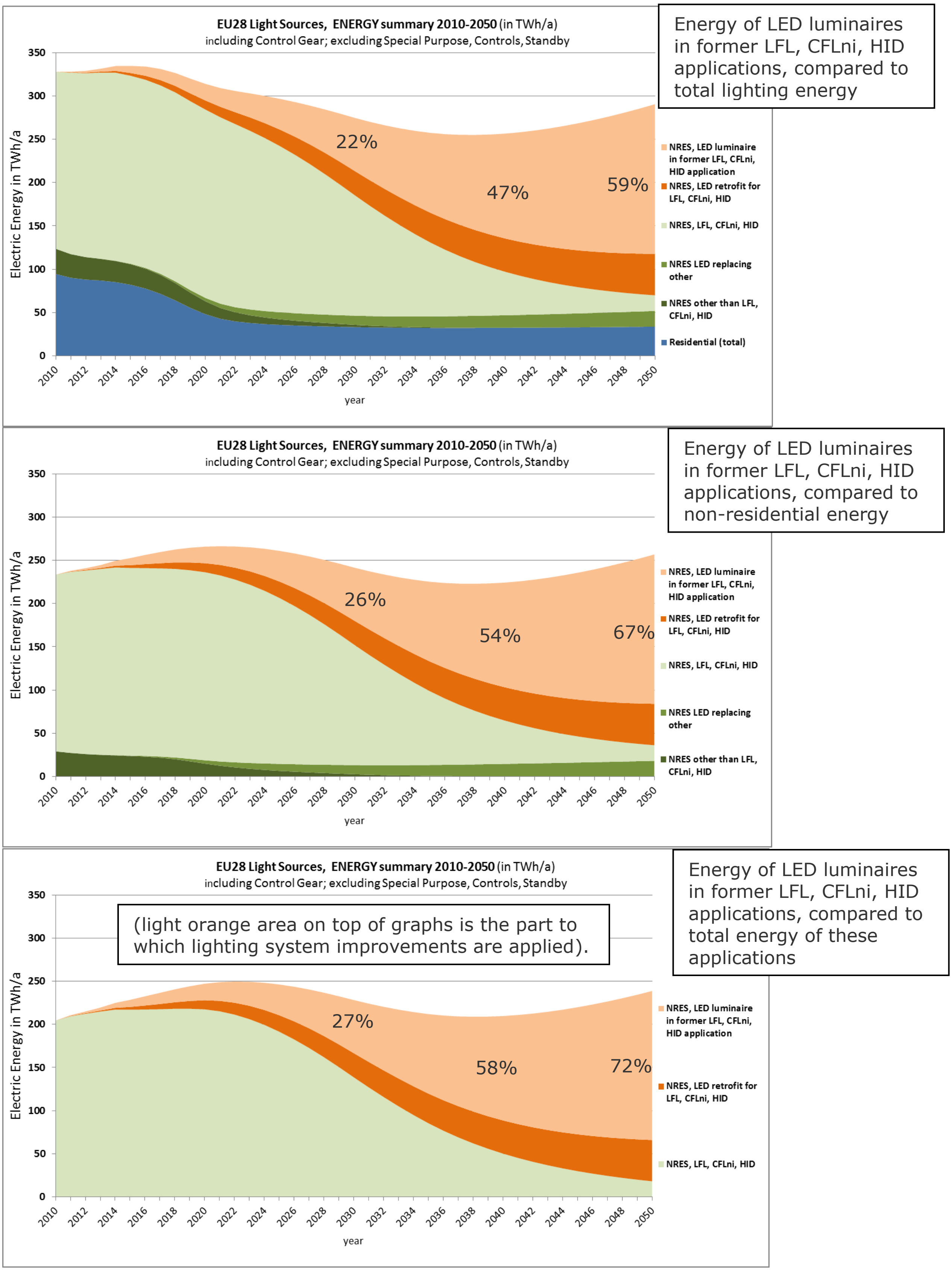


Figure 7-6 MELISA electric energy (TWh/a) for the light source BAU-scenario and share represented by integrated LED luminaires in former LFL-, CFLni- and HID-applications

In the ECO scenario for light sources, LFL-, CFLni- and HID-lamps are phased-out on varying dates between 2020 and 2024. This leads to a faster shift towards LED. E.g. the last figure above for the BAU scenario would change in the ECO-scenario to:

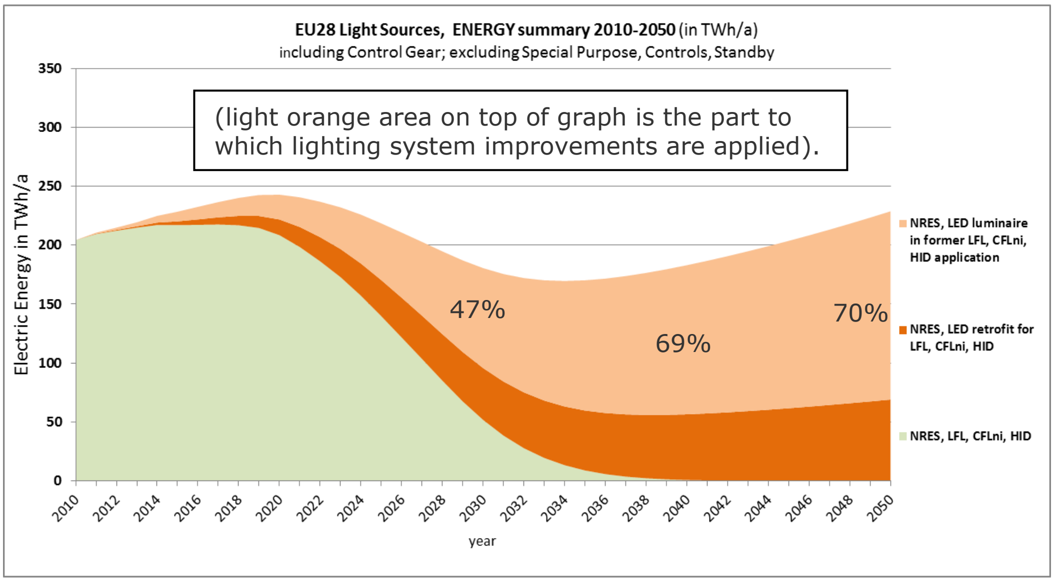


Figure 7-7 MELISA electric energy (TWh/a) for the light source ECO-scenario and share represented by integrated LED luminaires in former LFL-, CFLni- and HID-applications

7.4.6 Details from MELISA model on energy costs

Energy costs are calculated multiplying the electricity consumption (E_{before} or E_{after}) by the non-residential electricity rates (euros/kWh) already defined in MELISA.
The reference for rates up to 2013 is Eurostat tariff group Ie (according to old 2007 methodology): "annual consumption of 2 000 MWh, maximum demand of 500kW and annual load of 4 000 hours".
For the years following 2013 an escalation rate of 4% per year (excluding inflation) is applied. For the scenario analyses rates are not discounted. The rates are in fixed 2010 euros, exclusive VAT: 0.134 euros/kWh in 2016, 0.157 in 2020, 0.191 in 2025, 0.232 in 2030, 0.343 in 2040, 0.508 in 2050.

7.4.7 Details from MELISA modelon capital expenditure

<u>General approach:</u>
Capital expenditure (Capex) for the various reference cases and associated designs have been reported in Task 2 or Task 4 [239]. These values include the acquisition cost for the luminaires (including the first light sources and control gear), the labour costs for luminaire installation, the additional design mark-up (for optimised designs) and the additional control costs (for designs with lighting controls). There are no additional costs for the improvement of surface reflections. Building related costs to improve daylight availability, such as installation of roof lights, changes to windows, installation of blinds, etc. have not been taken into account.

[239] Or otherwise they can be found in the underlying Excel sheets.

These Capex data are approximate and preliminary. The main reason for this is that the study does not include MEErP Tasks 5 and 6, so that no full gathering of cost information has been performed.

The reported Capex for base designs refer to a solution with classical technology luminaires. However, in this scenario analysis the energy considered for the base design is the one for integrated LED luminaires from MELISA[240]. Therefore, for honesty of comparison between energy savings and monetary expenses, the costs of LED luminaires should be considered also for the base design. Consequently, the Capex for the base design is considered to be identical to the reported Capex for the optimised design (that always uses a LED luminaire), but subtracting the design mark-up (4 euros/m^2 for indoor; 3% for outdoor).

The Capex values for the reference designs are assumed to be valid for 2016. The reduction in future years (due to increase in luminaire quantities sold, due to optimisation of the luminaire production, and due to the price decrease for LED light sources) is assumed to follow the same trend as for high-end LED light sources in MELISA[241]. This means that Capex values reduce to 62% of their 2016 value in 2020, 43% in 2025 and 36% in 2030 and beyond.

The original Capex values (per room area or per km road length) are converted to specific values per kilo-lumen installed luminous flux (at light source level), i.e. they are expressed in euros/klmls[242]. Separate values are computed for the base design, optimised design and optimised design with controls. Two sets of average specific Capex values have been determined, respectively for application to the LFL- and CFLni-application groups of MELISA (indoor reference cases except large manufacturing halls) and to the HID-application group (outdoor reference cases and large manufacturing halls). In MELISA these Capex averages in euros/klmls are multiplied by the EU-28 total sold luminous light source flux (klmls) in a given year to determine the EU-28 total Capex.

Specific Capex in euros/klmls for indoor reference cases:

For designs for indoor reference cases, the Capex is originally defined for reference spaces with a defined area in m^2 (e.g. office, corridor, shop, manufacturing hall). Consequently an expenditure in euros/m^2 can be calculated (see Table 7-11 left hand part). Multiplying these values by the associated EU-28 area (m^2), the total EU-28 expenditure can be computed for each reference case and associated design. By summing all reference cases, the EU-28 total expenditure for all studied reference cases is determined, per type of design (base, optimised, optimised+controls).
In a similar way the EU-28 total installed luminous flux at light source level (klmls) can be computed for the same lighting system designs.

Dividing the former by the latter an average specific Capex in euros/klmls is derived (see Table 7-11 right hand part) for the studied indoor reference cases (excluding large manufacturing halls). This leads to 42.2 euros/klmls for the average base design, 65.6 euros/klmls for the average optimised design, and 77.4 euros/klmls for the average optimised design with controls (with or without additional surface reflection improvements).

[240] As explained before, this is done to avoid energy savings due to light source efficacy improvements being counted twice, first in MELISA and then in lighting system improvements.
[241] See Task 7 report of the Lot 8/9/19 light sources study.
[242] klmls = kilo-lumens installed luminous flux (klm) at light source (ls) level. The indication 'klmls' instead of 'klm' is used to avoid confusion with the lumen output of the luminaires.

If system improvements are assumed to apply also to non-studied cases, the same average specific Capex for the studied cases can be assumed to apply to all LFL- and CFLni-applications in MELISA. If system improvements are assumed not to apply to non-studied cases, it is assumed that the Capex for these cases will be equal to the average base design Capex of the studied cases. The overall average Capex (including non-studied cases) then becomes 42.2 euros/klmls for the base design, 53.4 euros/klmls for the optimised design, and 59.1 euros/klmls for the optimised design with controls.

Table 7-11 Specific capital expenditure (Capex/m^2 and Capex/klmls) for acquisition and installation of LED-luminaires, optimising of design, and addition of lighting controls, for LEDs in former LFL- and CFLni-applications (assumed valid for 2016)

Capex in euros/m^2 and euros/klmls (klmls = kilo-lumen at light source level) **(preliminary data)**	CAPEX, in euros / m^2					CAPEX, in euros / klmls			
	Base Case	Optimised Design	Optimised Design & Controls	Optimised Design & Controls & Surfaces		Base Case	Optimised Design	Optimised Design & Controls	Optimised Design & Controls & Surfaces
cellular, ceiling mounted (incl. general small offices)	43.31	47.31	57.60	57.60		41.8	67.6	82.3	82.3
cellular, suspended (incl. general small offices)	74.18	78.18	88.47	88.47		68.7	92.7	104.9	104.9
open offices, ceiling mounted	42.11	46.11	56.11	56.11		42.0	67.8	82.5	82.5
open offices, suspended	57.69	61.69	69.70	69.70		68.7	94.0	106.2	106.2
corridors (incl. all circulation areas, and toilets etc.)	19.79	23.79	29.58	29.58		47.5	85.7	106.5	106.5
shops > 30 m2, large (DIY 8000 m2)	27.41	31.41	32.14	32.14		30.0	35.2	36.0	36.0
shops > 30 m2, medium (supermarket 1200 m2)	37.12	41.12	42.00	42.00		35.4	39.3	40.2	40.2
manufacturing, large halls (6272 m2)	*3.74*	*7.74*	*8.30*	*8.30*		*10.0*	*34.2*	*36.7*	*36.7*
manufacturing, small workshops (392 m2)	14.26	18.26	20.55	20.55		17.1	43.9	49.5	49.5
storeroom/warehouse, general (7000 m2)	3.36	7.36	7.86	7.86		14.5	36.2	38.7	38.7
storeroom/warehouse, racks (600 m2)	15.02	15.02	21.10	21.10		19.0	19.0	26.7	26.7
all studied reference cases, average*	**29.09**	**32.83**	**38.75**	**38.75**		**42.2**	**65.6**	**77.4**	**77.4**
Non-studied cases, when assuming no system improvements	29.09	29.09	29.09	29.09		42.2	42.2	42.2	42.2
Overall average when assuming no system improvements for non-studied cases						**42.2**	**53.4**	**59.1**	**59.1**

* Averages do not include large manufacturing halls, which are HID-related, see below

Specific capex in euros/klmls for outdoor and large manufacturing hall reference cases:

For designs for outdoor reference cases, the Capex is originally defined per kilometre road length. Multiplying the Capex per km by the estimated EU-28 total km lit road length for each reference case, and adding the Capex for large manufacturing halls (derived from *Table 7-11*), the EU-28 total Capex over all reference cases can be derived, for the base design, the optimised design and the optimised design with controls.

In a similar way the EU-28 total installed luminous flux at light source level (klmls) can be computed for the same lighting system designs.
Dividing the former by the latter an average specific Capex in euros/klmls is derived (see *Table 7-12*) for the studied HID-related reference cases (roads and indoor large manufacturing halls). This leads to 33.2 euros/klmls for the average base design, 65.8 euros/klmls for the average optimised design, and 76.6 euros/klmls for the average optimised design with controls.

If system improvements are assumed to apply also to non-studied cases, the same average specific Capex for the studied cases can be applied to all HID-applications in MELISA. If system improvements are assumed not to apply to non-studied cases, it is assumed that the average base design Capex of the studied cases will apply to the non-studied cases. The overall average Capex then becomes 33.2 euros/klmls for the base design, 48.8 euros/klmls for the optimised design, and 54.0 euros/klmls for the optimised design with controls.

Table 7-12 Specific capital expenditure (Capex in euros/klmls) for acquisition and installation of LED-luminaires, optimising of design, and addition of lighting controls, for LEDs in former HID-applications (assumed valid for 2016)

Capex in euros/klmls (klmls = kilo=lumen at light source level) **(preliminary data)**	Base Case	Optimised Design	Optimised Design & Controls
motorways	24.44	48.37	60.29
main or national roads	28.42	43.89	52.47
secondary or regional, rural or mixed residential	29.12	58.17	67.50
secondary or regional, mixed conflict	29.23	54.41	65.05
other roads, mixed traffic	38.46	79.37	98.65
other roads, residential streets P4	77.89	132.60	153.88
other roads, residential streets M5	70.81	104.56	121.34
indoor: large manufacturing halls	9.99	34.20	36.66
weighted average for studied cases	**33.17**	**65.84**	**76.64**
outdoor not covered (assuming no savings)	33.17	33.17	33.17
indoor not covered (assuming no savings)	33.17	33.17	33.17
weighted average assuming no systems improvements for non-studied cases	**33.17**	**48.81**	**53.98**

7.4.8 Details from MELISA modelon repair and maintenance costs

Differences in repair & maintenance costs between the lighting system design options have not been taken into account. Considering that all options use LED products, these differences are assumed to be negligible. The influence of lighting controls (i.e. more frequent switching or dimming) on the lifetime of lighting system components could not be assessed in the context of this study.

7.4.9 Details from MELISA modelon Greenhouse gas (GHG) emissions

Greenhouse gas emissions (GHG emissions in Mt CO_2 equivalent/a) are computed multiplying the electricity consumption (E_{after} or E_{before}) by the Global Warming Potential (GWP) of electricity use (expressed in kg CO_2 equivalent / kWh).

The GWP-values already defined in MELISA have been used[243]. These values decrease with time: 0.392 kgCO_2eq/kWh in 2016, 0.38 in 2020, 0.36 in 2025, 0.34 in 2030, 0.30 in 2040, 0.26 in 2050.

7.5 Environmental and Economic impacts

Objective:
This section presents the results of scenario analysis, i.e. the impacts of the lighting system design options on electricity consumption, greenhouse gas emissions and user costs. Considering that cost data are preliminary, at this stage no analysis has been made of sector revenues and associated jobs.

7.5.1 Introduction

The calculated impacts of lighting system improvements are presented below with respect to three different reference scenarios for light sources, as defined in the Task 7 report of the Lot 8/9/19 light sources study[244]:

- Light source BAU-scenario (without energy label improvement)
- Light source ECO 80+120 scenario (without energy label improvement)
- Light source ECO 80+120+LBL scenario (with energy label improvement)

Impacts for each reference scenario are presented in a separate paragraph.

For each reference scenario the following annual and cumulative (from 2016) impacts are considered:

- Electricity saving
- Greenhouse Gas Emission reduction
- Monetary saving or additional expense for users

For each reference scenario, the impacts are presented for three design options:

- Improved design (application of Flux Factor)
- Improved design with controls (application of Flux Factor and Hour Factor)
- Improved design with controls and surface reflectance improvements (application of Flux Factor and reduced Hour Factor)[245]

For each of these designs, the impacts are presented assuming that system improvements will apply only to the reference cases that have been studied, i.e. there are no savings on cases that have not been studied and F_{phi}=1 and F_{hour}=1 for these cases. The rationale for this is that for the non-studied cases there are no reference values for LENI or AECI (kWh/m^2/a) so that no ecodesign efficiency requirements could be formulated.

[243] The MELISA GWPelec on their turn are identical to those used in the Ecodesign Impact Accounting, see also https://ec.europa.eu/energy/sites/ener/files/documents/Ecodesign%20Impacts%20Accounting%20%20-%20status%20January%202016%20-%20Final-20160607%20-%20N....pdf

[244] http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task7%20Final%2020151031.pdf

[245] The improvement of surface reflections is considered only for indoor spaces. For road lighting the same data apply as for ‘optimised design with controls’.

The data presented are based on an assumption of the introduction of measures in 2020.

The savings presented are for lighting system improvements only: savings due to increase in efficacy of light sources are not included (because they are already considered in the reference scenarios from MELISA).

As explained in section 7.4.4, impacts of lighting system improvements are evaluated in relation to the electricity consumed by integrated LED luminaires. In all reference scenarios this consumption increases with time because there is a shift from classical technologies to LEDs (see also *Figure 7-6* and *Figure 7-7*). The increase is smaller after introduction of lighting system improvements, but the graphs still show an increase. The reason for this is that graphs show only electricity consumed by (increasing quantities of) LED luminaires; the overall non-residential lighting energy is decreasing.

The electricity savings and GHG emission reductions presented are considered to be maximum possible values. Although the assumed base designs are probably better than the average current practice (which would suggest that higher savings are possible), the Flux Factors and Hour Factors for the optimised designs are conceived by the study team as the lowest feasible values (BAT values) and not as average values for the situation after introduction of a regulation on lighting system performance.

Monetary data presented in this report are preliminary and roughly indicative. Considering that the study did not perform the MEErP Task 5 and 6 stages, a full study of cost data has not been performed. Revenues and employment in the lighting systems' sector depend on the monetary data and have therefore not been studied so far. A follow-up study to further investigate the monetary and employment aspects of lighting system improvements is recommended.

7.5.2 System improvement impacts versus light source BAU

The BAU scenario of MELISA assumes that no new ecodesign measures will be introduced for light sources, i.e. existing regulations 244/2009, 245/2009 and 1194/2012 remain in force. In general these regulations allow most LFL, CFLni and HID-lamps to remain on the market (with the exception of high-pressure mercury lamps and the worst performing quartz metal-halide lamps). The expected effects of regulation 245/2009 stage 3 (2017) are included in the BAU scenario. The energy labelling regulation 874/2012 is assumed to remain unchanged.

The BAU scenario includes a shift from classical lighting technologies towards LED lighting products (retrofit lamps and integrated LED luminaires), according to current trends and expected future developments. For details on the assumptions made, see the Task 7 report of the Lot 8/9/19 preparatory study[246].

The table and graphs in this paragraph show the impacts of lighting system improvements with respect to the light source BAU scenario.

[246] http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task7%20Final%2020151031.pdf

For the optimised system design, electricity savings are 6 TWh/a in 2025, 12 TWh/a in 2030, 24 TWh/a in 2040 and 33 TWh/a in 2050. This trend of savings increasing with time is found for all impact parameters. It derives from the fact that system improvements are applied to a reference electricity consumption (for integrated LED luminaires) that increases with time, and from the fact that the BAU scenario, from the point of view of lighting system performance, is a freeze scenario[247].
Adding lighting controls to an optimised system design increases the savings and improving indoor surface reflectance further increases them. E.g. in 2030 the electricity savings for the optimised design are 12 TWh/a, adding controls increases this to 20 TWh/a while also improving the surface reflectance further increases the savings to 23 TWh/a.

Depending on the design option, cumulative electricity savings from 68 to 127 TWh are estimated for 2030 and 544 to 1102 TWh for 2050.

Greenhouse gas emission reductions are linked to electricity savings by means of the GWP for electricity (section 7.4.9). Depending on the design option, from 9 to 18 $MtCO_2$eq./a can be avoided in 2050, or cumulative since 2016 from 163 to 329 $MtCO_2$eq.

To obtain the energy savings and GHG emission reductions, investments have to be made in optimised designs and controls. These are reported in the table as negative capital expenditure savings. These additional expenses are amply compensated by lower electricity costs and lead to a saving in total user cumulative expenditure by approximately 2025, albeit that this economic analysis should be considered to be preliminary in nature.

[247] From the point of view of light sources the BAU scenario is not a freeze scenario because there is anyway a shift towards LED lighting, and eventually, on the long term, the BAU scenario becomes identical to the ECO scenario for light sources and savings for the ECO scenario go to zero (except for influences of energy labelling improvements). However, from the point of view of lighting systems, the BAU scenario assumes that the 2016 average performance and penetration of lighting systems will remain the same in future years, i.e. it is assumed that without introduction of measures for lighting system there will be no system improvements.

Table 7-13 Summary of EU-28 total savings due to lighting system improvements, with respect to the Lot 8/9/19 BAU scenario (without labelling improvements).

Impact Parameter	**Design option**	**2025**	**2030**	**2040**	**2050**
Electricity (TWh/a)[2,3]	Reference (BAU)	36	62	121	173
	Optimised	30	50	98	140
	Optimised +Controls	26	42	82	117
	Opt.+Cntrl.+Surfaces[5]	25	38	73	103
Annual Electricity Saving (TWh/a)	Optimised	6	12	24	33
	Optimised +Controls	10	20	39	56
	Opt.+Cntrl.+Surfaces	11	23	48	70
Cumulative Electricity Saving from 2016 (TWh)	Optimised	20	68	254	544
	Optimised +Controls	32	109	417	904
	Opt.+Cntrl.+Surfaces	36	127	501	1102
Annual GHG Emission Reduction ($MtCO_2eq/a$)	Optimised	2	4	7	9
	Optimised +Controls	3	7	12	15
	Opt.+Cntrl.+Surfaces	4	8	15	18
Cumulative GHG Emission Reduction from 2016 ($MtCO_2eq$)	Optimised	7	24	83	163
	Optimised +Controls	12	38	136	271
	Opt.+Cntrl.+Surfaces	13	45	163	329
Annual Capital Expenditure Saving (bn euros/a)[1]	Optimised	-0.5	-0.6	-0.9	-1.2
	Optimised +Controls	-1.2	-1.7	-2.3	-3.0
	Opt.+Cntrl.+Surfaces	-1.2	-1.7	-2.3	-3.0
Annual Energy Cost Saving (bn euros/a)	Optimised	1.1	2.8	8.1	16.9
	Optimised +Controls	1.8	4.6	13.5	28.5
	Opt.+Cntrl.+Surfaces	2.1	5.4	16.6	35.3
Annual User Expense Saving (bn euros/a)[1,4]	Optimised	0.7	2.2	7.2	15.7
	Optimised +Controls	0.6	2.9	11.3	25.5
	Opt.+Cntrl.+Surfaces	0.9	3.7	14.3	32.3
Cumulative User Expenditure Saving from 2016 (bn euros)[1]	Optimised	1.2	8.8	56	171
	Optimised +Controls	-0.1	9.3	80	265
	Opt.+Cntrl.+Surfaces	0.7	13.0	103	338

1: A negative saving indicates an additional expense. Capital Expenditure data and User Expense data are preliminary (further study recommended)
2: These data refer only to integrated LED luminaires substituting LFL, CFLni or HID-lamps in non-residential applications. Electricity for non-studied cases is included. The figures do not indicate the total electricity for non-residential lighting (see *Figure 7-6*).
3: Electricity includes the light source and the control gear. Electricity for lighting controls and for standby is not included. Special purpose applications are excluded.
4: User Expenditure: sum of additional Capital Expenditure and savings on Electricity Cost
5: Adds improved surface reflections for indoor spaces. No additional effect for road lighting.

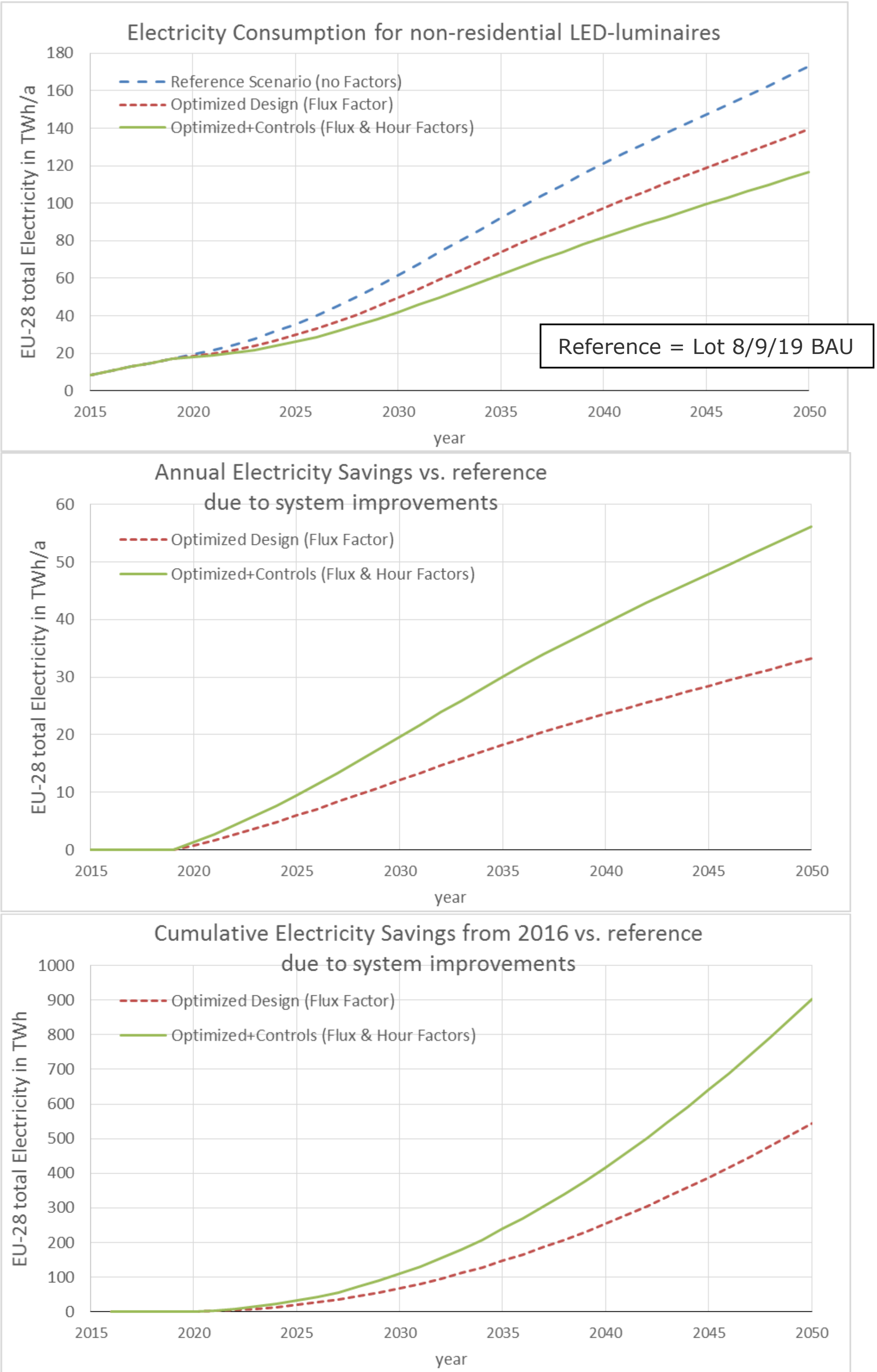


Figure 7-8 Electricity savings due to system improvements with respect to the Lot 8/9/19 BAU scenario (without labelling improvements)

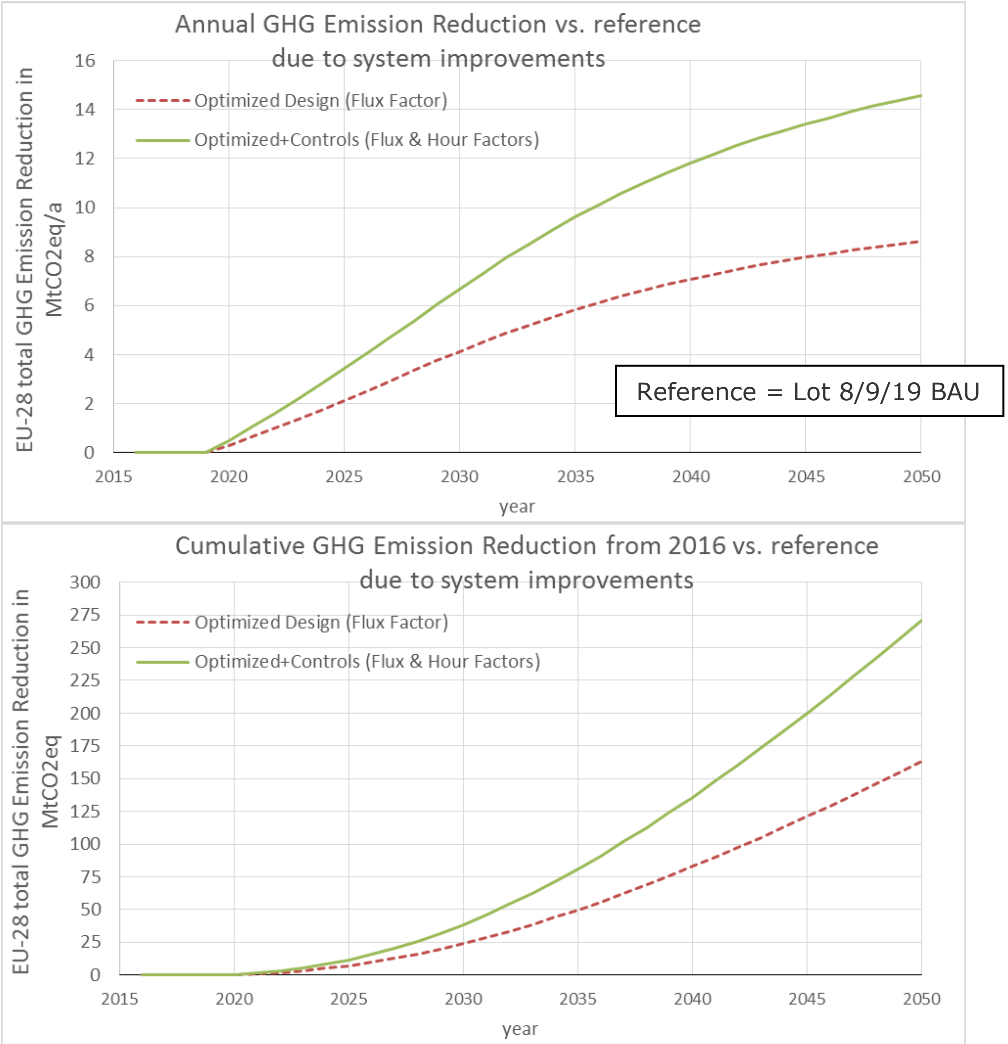


Figure 7-9 Greenhouse gas emission reduction in $MtCO_2eq$[248] due to system improvements with respect to the Lot 8/9/19 BAU scenario (without labelling improvements)

[248] $MtCO_2eq$ = Mega tonnes carbon dioxide equivalent. Mt = 1 billion kilos. For comparison, the total EU-28 GHG emission is 4721 Mt CO_2 eq (source: EEA, GHG Inventory 2012. Total for EU-28 excl. land use, land-use change and forestry (LULUCF).)

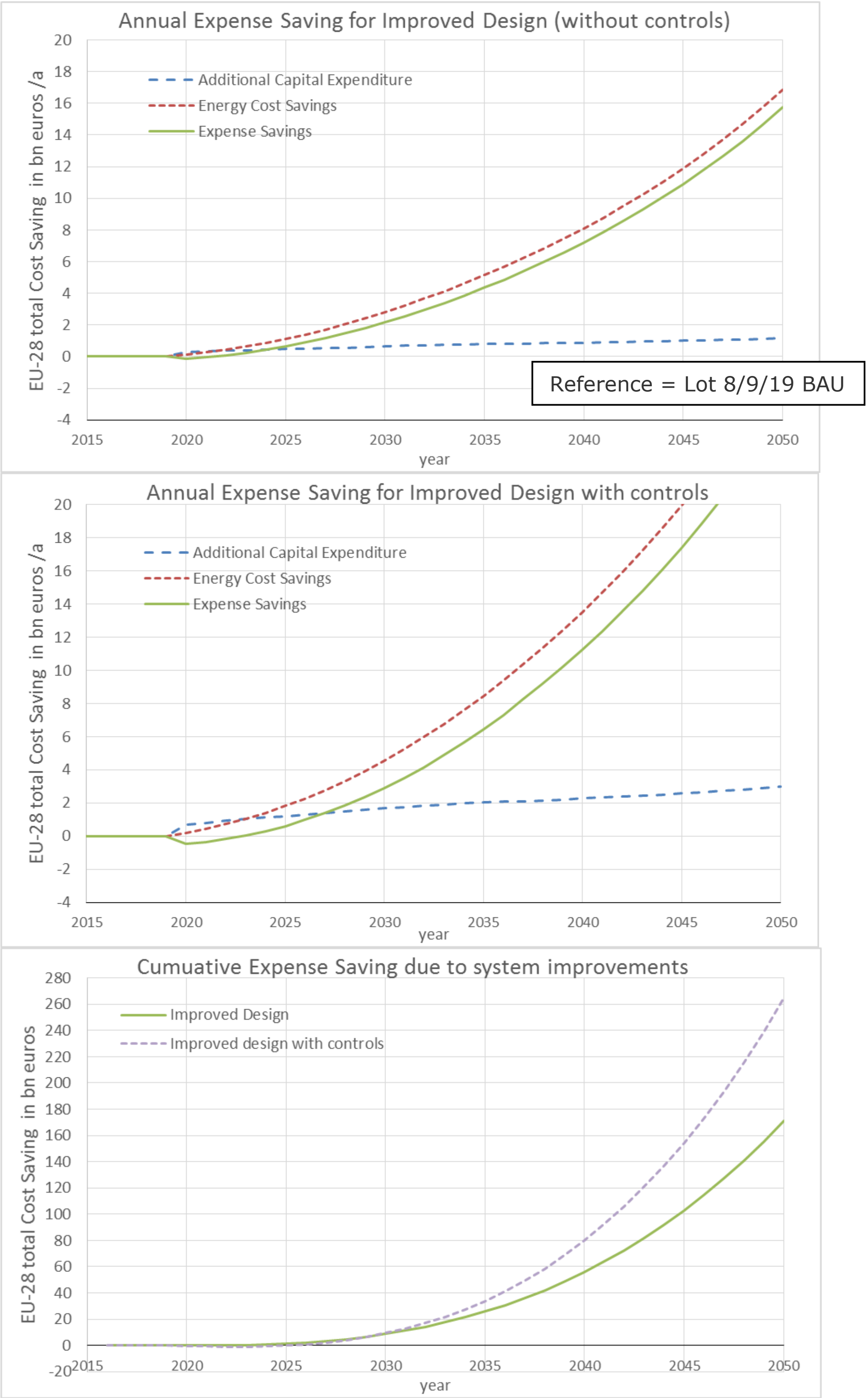


Figure 7-10 Cost savings due to system improvements with respect to the Lot 8/9/19 BAU scenario (without labelling improvements) (preliminary)

7.5.3 System improvement impacts versus light source ECO 80+120

The ECO 80+120 scenario of MELISA assumed that a reference light source efficacy of 80 lm/W would be imposed in 2020, followed by 120 lm/W in 2024. This would phase-out all CFLni and the worst performing LFL and HID-lamps (some T8, some HPS and MH quartz) by 2020, and all classical technology lamps by 2024, leading to a LED-only scenario. For details on the assumptions made, see the Task 7 report of the Lot 8/9/19 preparatory study[249].

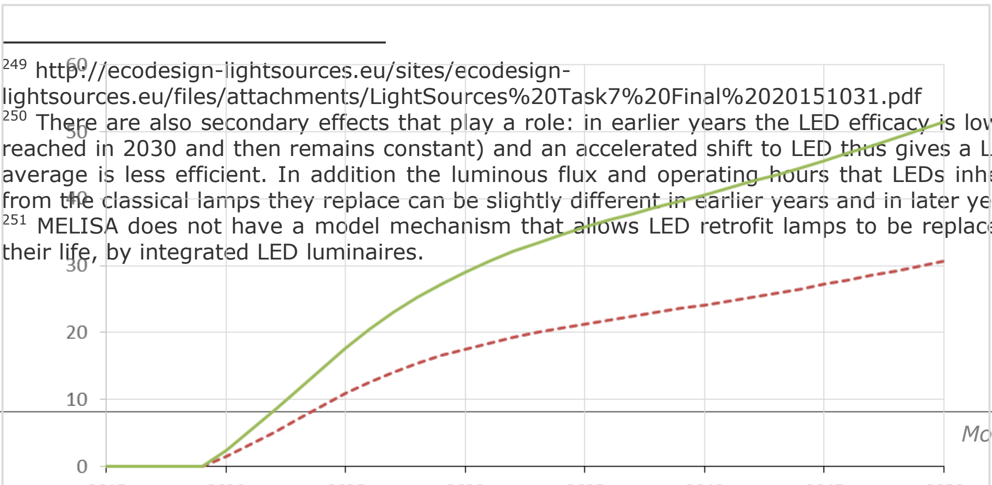
For the use of MELISA in the scenario analysis for lighting system improvements, the main difference with the BAU scenario of the previous paragraph is that the shift towards LED is accelerated.

The energy labelling regulation 874/2012 is assumed to remain unchanged (this is the difference with the analysis in the next paragraph).

The ECO 80+120 scenario received mixed comments by stakeholders, and might undergo changes before being agreed on to become part of a new regulation, but to date (August 2016) it is the only well-documented light source ECO scenario that can be used as a reference. The scenario can therefore be conceived as an initial light sources ECO scenario. The savings due to lighting system improvements calculated with BAU as a reference (previous paragraph) and those with ECO 80+120 as a reference (this paragraph) are seen as reference points with actual savings only quantifiable once a new lighting product regulation has been agreed on.
The table and graphs in this paragraph show the impacts of lighting system improvements with respect to the light source ECO 80+120 scenario without energy labelling improvement.

Due to the accelerated shift towards LED in the ECO 80+120 scenario, the quantity of integrated LED luminaires in early years of the analysis period is higher than in the BAU scenario and therefore their electricity consumption is also higher. The same system improvement factors F_{phi} and F_{hour} thus act on a higher reference energy (E_{before}) and consequently electricity savings are also higher. This also means that lighting system improvements are introduced faster than in the BAU scenario.
However, this situation changes in later years: around 2040 the electricity consumption of LED luminaires is more or less the same in the ECO and BAU scenarios, and in 2050 it is even smaller in ECO than in BAU. The reason for this is that an early shift to LED means relatively more LED retrofit lamps and relatively less integrated LED luminaires (according to MELISA assumptions). Consequently, by e.g. 2050, the quantity of LED luminaires is smaller than it was in the BAU scenario, because LED retrofits cover a larger share of the stock[250] [251]. See *Figure 7-11* for illustration.

Cumulative electricity savings over the 2016-2050 period are slightly higher using the ECO 80+120 scenario as a reference than using the BAU scenario.



[249] http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task7%20Final%2020151031.pdf
[250] There are also secondary effects that play a role: in earlier years the LED efficacy is lower (maximum is reached in 2030 and then remains constant) and an accelerated shift to LED thus gives a LED stock that on average is less efficient. In addition the luminous flux and operating hours that LEDs inherit in the model from the classical lamps they replace can be slightly different in earlier years and in later years.
[251] MELISA does not have a model mechanism that allows LED retrofit lamps to be replaced, at the end of their life, by integrated LED luminaires.

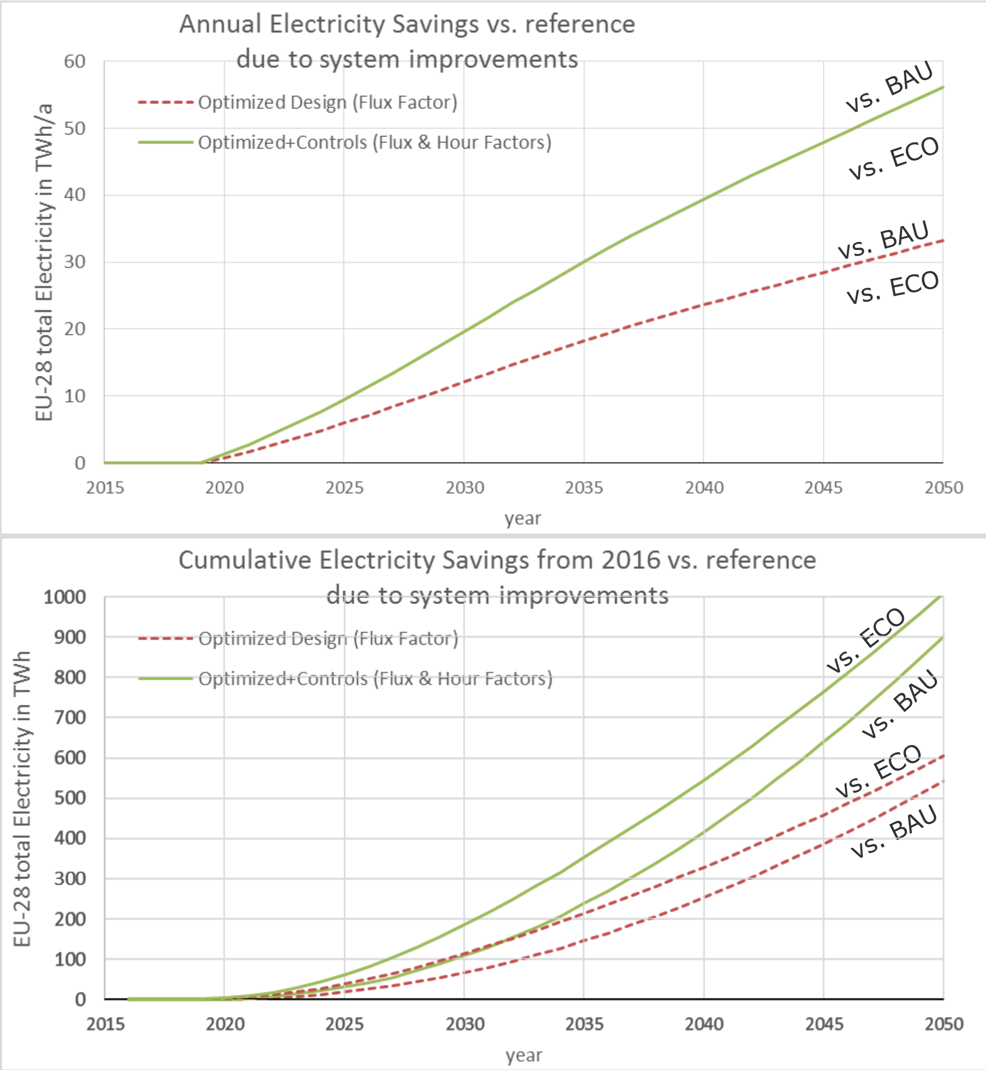


Figure 7-11 Comparison of Electricity savings due to system improvements with respect to the light source BAU scenario and with respect to the light source ECO 80+120 scenario.

For the optimised system design, electricity savings are 11 TWh/a in 2025 (was 6 for BAU as a reference), 18 TWh/a in 2030 (was 12 for BAU), 24 TWh/a in 2040 (was 24 also for BAU) and 31 TWh/a in 2050 (was 33 for BAU).
Adding lighting controls to an optimised system design increases the savings and improving indoor surface reflectance further increases them. E.g. in 2030 the electricity savings for the optimised design are 18 TWh/a, adding controls increases this to 29 TWh/a and improving also surface reflectance further increases to 35 TWh/a.

Depending on the design option, cumulative electricity savings from 113 to 219 TWh are estimated for 2030 and 604 to 1234 TWh for 2050.
Greenhouse gas emission reductions are linked to electricity savings by means of the GWP for electricity (section 7.4.9). Depending on the design option, from 8 to 17 $MtCO_2eq$./a can be avoided in 2050, or cumulative from 2016 ranges from 185 to 376 $MtCO_2eq$.

To obtain the energy savings and GHG emission reductions, investments have to be made in optimised designs and controls. These are reported in the table as negative capital expenditure savings. These additional expenses are amply compensated by lower electricity costs and lead to a net saving in total user cumulative expense by approximately 2025 (depending on the design option). This economic analysis should be considered to be preliminary.

Table 7-14 Summary of EU-28 total savings due to lighting system improvements, with respect to the Lot 8/9/19 ECO 80+120 scenario (without labelling improvements).

Impact Parameter	**Design option**	**2025**	**2030**	**2040**	**2050**
Electricity (TWh/a)[2,3] for LED luminaires	Reference	62	92	125	158
	Optimised	51	74	101	128
	Optimised +Controls	44	63	85	107
	Opt.+Cntrl.+Surfaces[5]	41	57	75	95
Annual Electricity Saving (TWh/a)	Optimised	11	18	24	31
	Optimised +Controls	18	29	41	52
	Opt.+Cntrl.+Surfaces	21	35	50	64
Cumulative Electricity Saving from 2016 (TWh)	Optimised	37	113	328	604
	Optimised +Controls	60	185	545	1009
	Opt.+Cntrl.+Surfaces	70	219	662	1234
Annual GHG Emission Reduction ($MtCO_2eq/a$)	Optimised	4	6	7	8
	Optimised +Controls	6	10	12	13
	Opt.+Cntrl.+Surfaces	7	12	15	17
Cumulative GHG Emission Reduction from 2016 ($MtCO_2eq$)	Optimised	14	40	108	185
	Optimised +Controls	22	65	180	308
	Opt.+Cntrl.+Surfaces	26	78	218	376
Annual Capital Expenditure Saving (bn euros/a)[1]	Optimised	-0.9	-0.7	-0.7	-1.0
	Optimised +Controls	-2.2	-1.8	-1.9	-2.7
	Opt.+Cntrl.+Surfaces	-2.2	-1.8	-1.9	-2.7
Annual Energy Cost Saving (bn euros/a)	Optimised	2.1	4.1	8.3	15.6
	Optimised +Controls	3.4	6.7	13.9	26.2
	Opt.+Cntrl.+Surfaces	3.9	8.2	17.2	32.2
Annual User Expense Saving (bn euros/a)[1,4]	Optimised	1.2	3.4	7.5	14.5
	Optimised +Controls	1.2	4.9	12.0	23.5
	Opt.+Cntrl.+Surfaces	1.7	6.4	15.3	29.6
Cumulative User Expense Saving from 2016 (bn euros)[1]	Optimised	2.0	14.7	71	181
	Optimised +Controls	-1.1	16.3	104	280
	Opt.+Cntrl.+Surfaces	0.7	23.4	135	358

1: A negative saving indicates an additional expense. Capital Expenditure data and User Expense data are preliminary (further study recommended)
2: These data refer only to integrated LED luminaires substituting LFL, CFLni or HID-lamps in non-residential applications. Electricity for non-studied cases is included. The figures do not indicate the total electricity for non-residential lighting (see *Figure 7-6*).
3: Electricity includes the light source and the control gear. Electricity for lighting controls and for standby is not included. Special purpose applications are excluded.
4: User Expense: sum of additional Capital Expenditure and savings on Electricity Cost
5: Adds improved surface reflections for indoor spaces. No additional effect for road lighting.

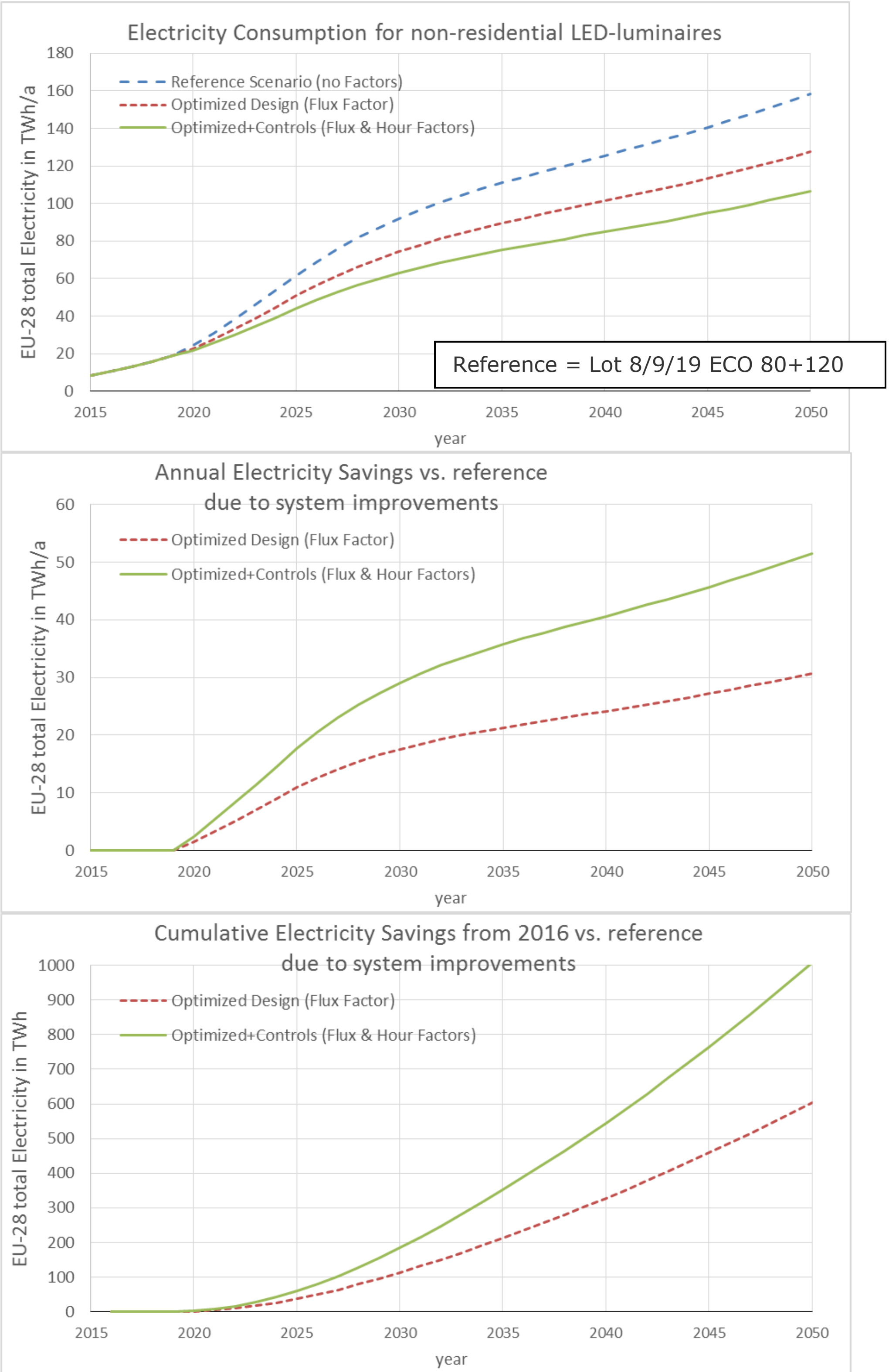


Figure 7-12 Electricity savings due to system improvements with respect to the Lot 8/9/19 ECO 80+120 scenario (without labelling improvements)

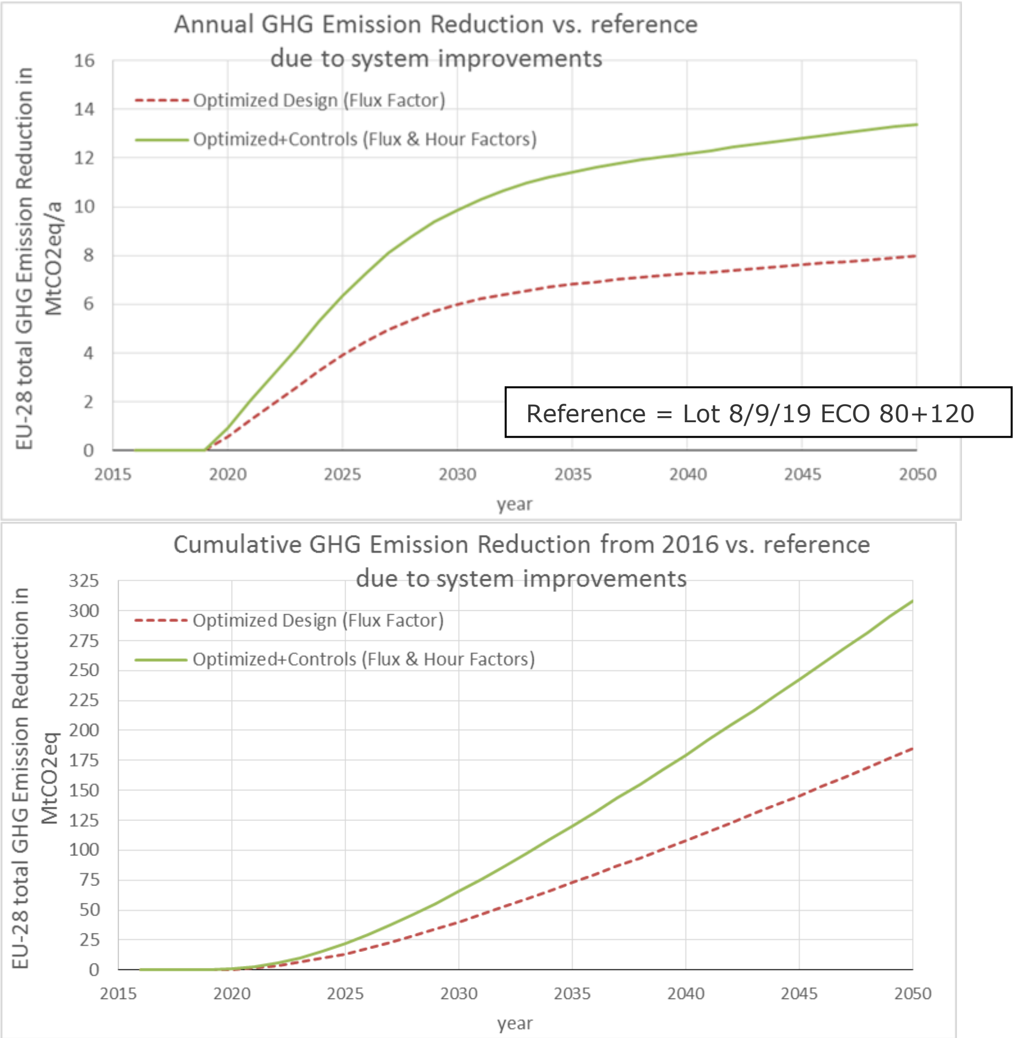


Figure 7-13 Greenhouse gas emission reduction in $MtCO_2eq$[252] due to system improvements with respect to the Lot 8/9/19 ECO 80+120 scenario (without labelling improvements)

[252] $MtCO_2eq$ = Mega tonnes carbondioxide equivalent. Mt = 1 billion kilos. For comparison, the total EU-28 GHG emission is 4721 Mt CO_2 eq (source: EEA, GHG Inventory 2012. Total for EU-28 excl. land use, land-use change and forestry (LULUCF).)

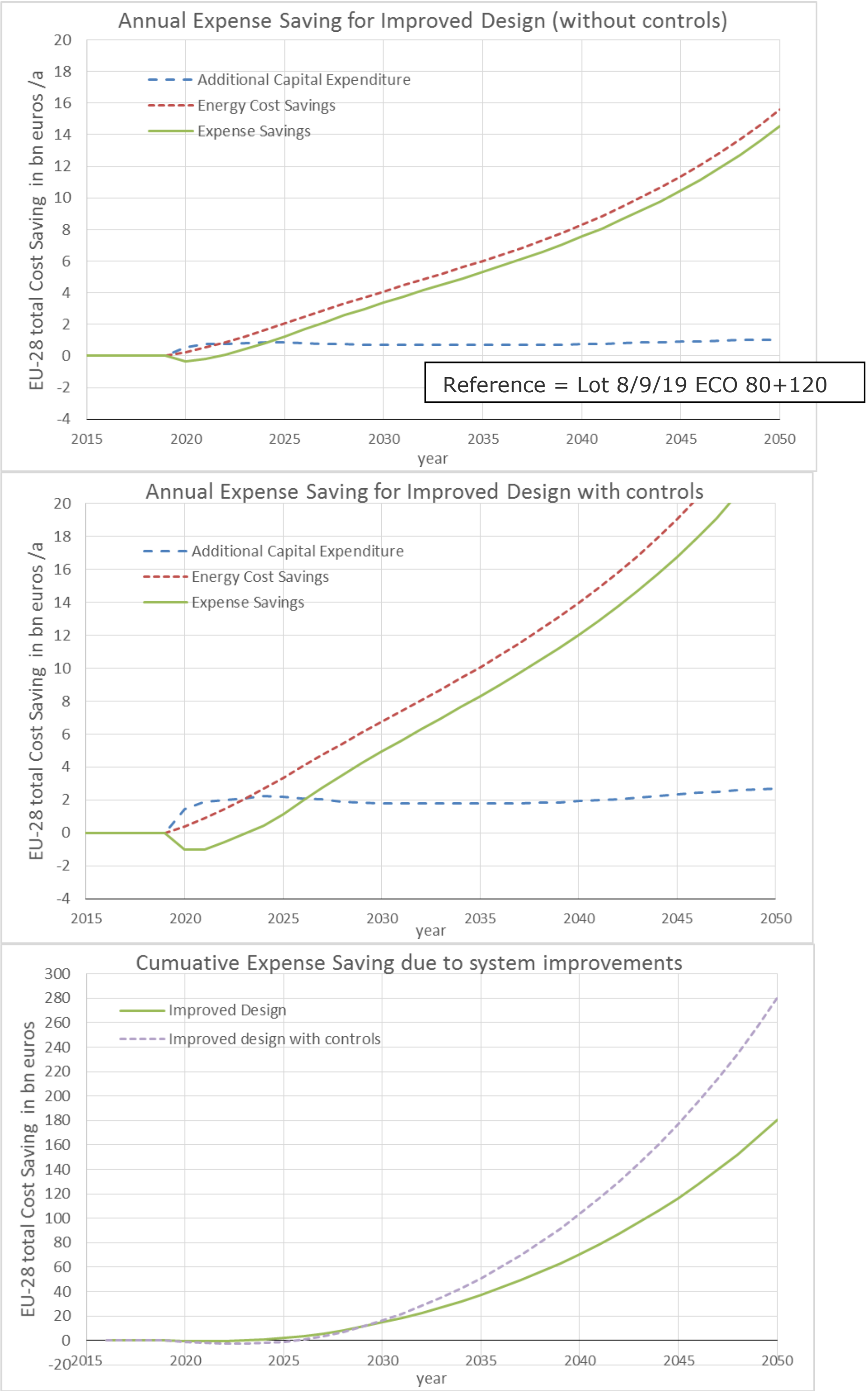


Figure 7-14 Cost savings due to system improvements with respect to the Lot 8/9/19 ECO 80+120 scenario (without labelling improvements) (preliminary)

7.5.4 System improvement impacts versus light source ECO 80+120+LBL

The Task 7 report of the Lot 8/9/19 preparatory study[253] also proposed improvements in the energy labelling of light sources (i.e. a change to regulation 874/2012). The assumed effect of these improvements was an increase in average LED light source efficacy by two energy label classes. For LEDs substituting LFL, CFLni and HID-lamps in the non-residential sector (High-End LEDs) this means applying an efficacy-time curve that reaches 225 lm/W in 2030 instead of a curve that reaches 208 lm/W in 2030 as used in the previous paragraph. See the reference for further details.

For the use of MELISA in the scenario analysis for lighting system improvements, the main difference with the ECO 80+120 scenario of the previous paragraph (without labelling improvements) is that LED light sources get a higher efficacy and thus consume less electricity. Consequently, savings due to lighting system improvements can be expected to be lower. See *Figure 7-15* for an illustration.
The decision on how to change regulation 874/2012 has not yet been taken (August 2016).

The table and graphs in this paragraph show the impacts of lighting system improvements with respect to the light source ECO 80+120+LBL scenario, with energy labelling improvement. Note that the proposed lighting design policy measures in section 7.3 can also contribute to achieving the proposed energy saving benefits from the ECO 80+120+LBL scenario, meaning that one has to select efficient light sources to achieve low LENI or AECI values.

As expected, savings for all lighting system impact parameters are smaller when taking the scenario with label improvements as a reference. This does not mean that the decision on energy label improvements should not be taken: the combined savings due to light source efficacy improvements and to lighting system improvements are in any case higher when the labelling system is made more effective.

For the optimised system design, electricity savings are 10 TWh/a in 2025 (as compared with 11 for ECO without LBL as a reference), 16 TWh/a in 2030 (as compared with 18 without LBL), 22 TWh/a in 2040 (as compared with 24 without LBL) and 28 TWh/a in 2050 (as compared with 31 without LBL).

Adding lighting controls to an optimised system design increases the savings and improving indoor surface reflectance further increases them. E.g. in 2030 the electricity savings for the optimised design are 16 TWh/a, adding controls increases this to 27 TWh/a and also improving surface reflectance further increases this to 32 TWh/a.

Greenhouse gas emission reductions are linked to electricity savings via means the GWP emissions factor (section 7.4.9). Depending on the design option, from 7 to 15 $MtCO_2eq$./a can be avoided in 2050, or if accounted cumulatively from 2016 ranging from between 170 to 347 $MtCO_2eq$.

To obtain the energy savings and GHG emission reductions, investments have to be made in optimised designs and controls. These are reported in the table as negative capital expenditure savings. These additional expenses are amply compensated by lower electricity costs and lead to a saving in total user cumulative expenditire by

[253] http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources%20Task7%20Final%2020151031.pdf

approximately 2025 (depending on the design option). This economic analysis should be considered to be preliminary.

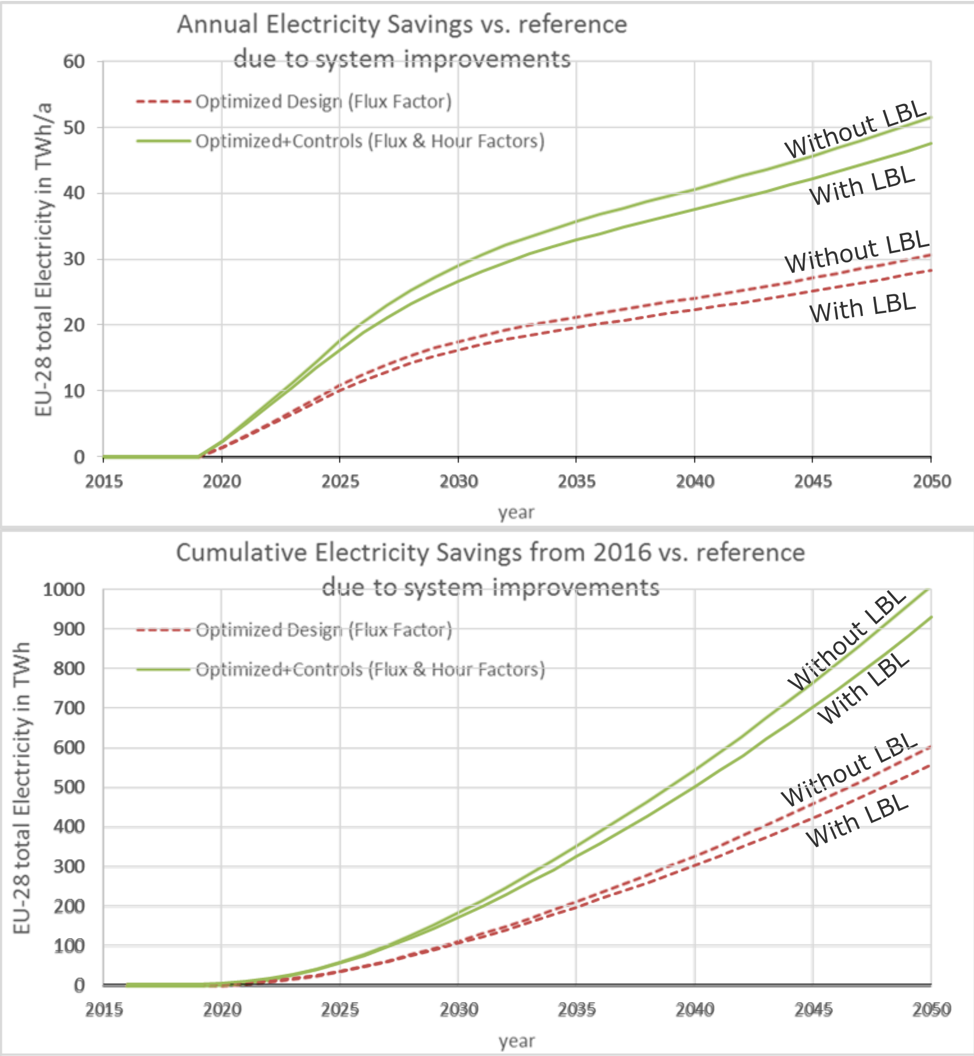


Figure 7-15 Comparison of Electricity savings due to system improvements with respect to the light source ECO 80+120 scenario with and without energy label improvement (LBL).

Table 7-15 Summary of EU-28 total savings due to lighting system improvements, with respect to the Lot 8/9/19 ECO 80+120+LBL scenario (with labelling improvements).

Impact Parameter	**Design option**	**2025**	**2030**	**2040**	**2050**
Electricity (TWh/a)[2,3] for LED luminaires	Reference	57	84	116	146
	Optimised	47	68	94	118
	Optimised +Controls	41	58	78	99
	Opt.+Cntrl.+Surfaces[5]	38	52	70	88
Annual Electricity Saving (TWh/a)	Optimised	10	16	22	28
	Optimised +Controls	16	27	38	48
	Opt.+Cntrl.+Surfaces	19	32	46	59
Cumulative Electricity Saving from 2016 (TWh)	Optimised	34	104	302	557
	Optimised +Controls	55	170	502	931
	Opt.+Cntrl.+Surfaces	64	202	610	1138
Annual GHG Emission Reduction ($MtCO_2eq/a$)	Optimised	4	6	7	7
	Optimised +Controls	6	9	11	12
	Opt.+Cntrl.+Surfaces	7	11	14	15
Cumulative GHG Emission Reduction from 2016 ($MtCO_2eq$)	Optimised	13	37	100	170
	Optimised +Controls	20	60	165	284
	Opt.+Cntrl.+Surfaces	24	71	201	347
Annual Capital Expenditure Saving (bn euros/a)[1]	Optimised	-0.9	-0.7	-0.8	-1.1
	Optimised +Controls	-2.3	-1.9	-2.0	-2.8
	Opt.+Cntrl.+Surfaces	-2.3	-1.9	-2.0	-2.8
Annual Energy Cost Saving (bn euros/a)	Optimised	1.9	3.7	7.7	14.4
	Optimised +Controls	3.1	6.2	12.9	24.2
	Opt.+Cntrl.+Surfaces	3.6	7.5	15.9	29.8
Annual User Expense Saving (bn euros/a)[1,4]	Optimised	1.0	3.0	6.9	13.3
	Optimised +Controls	0.8	4.3	10.9	21.4
	Opt.+Cntrl.+Surfaces	1.3	5.6	13.9	27.0
Cumulative User Expense Saving from 2016 (bn euros)[1]	Optimised	1.2	12.5	63	164
	Optimised +Controls	-2.6	12.2	90	251
	Opt.+Cntrl.+Surfaces	-1.0	18.7	119	323

1: A negative saving indicates an additional expense. Capital Expenditure data and User Expense data are preliminary (further study recommended)
2: These data refer only to integrated LED luminaires substituting LFL, CFLni or HID-lamps in non-residential applications. Electricity for non-studied cases is included. The figures do not indicate the total electricity for non-residential lighting (see *Figure 7-6*).
3: Electricity consumption includes the light source and the control gear. Electricity for lighting controls and for standby is not included. Special purpose applications are excluded.
4: User Expense: sum of additional Capital Expenditure and savings on Electricity Cost
5: Adds improved surface reflections for indoor spaces. No additional effect for road lighting.

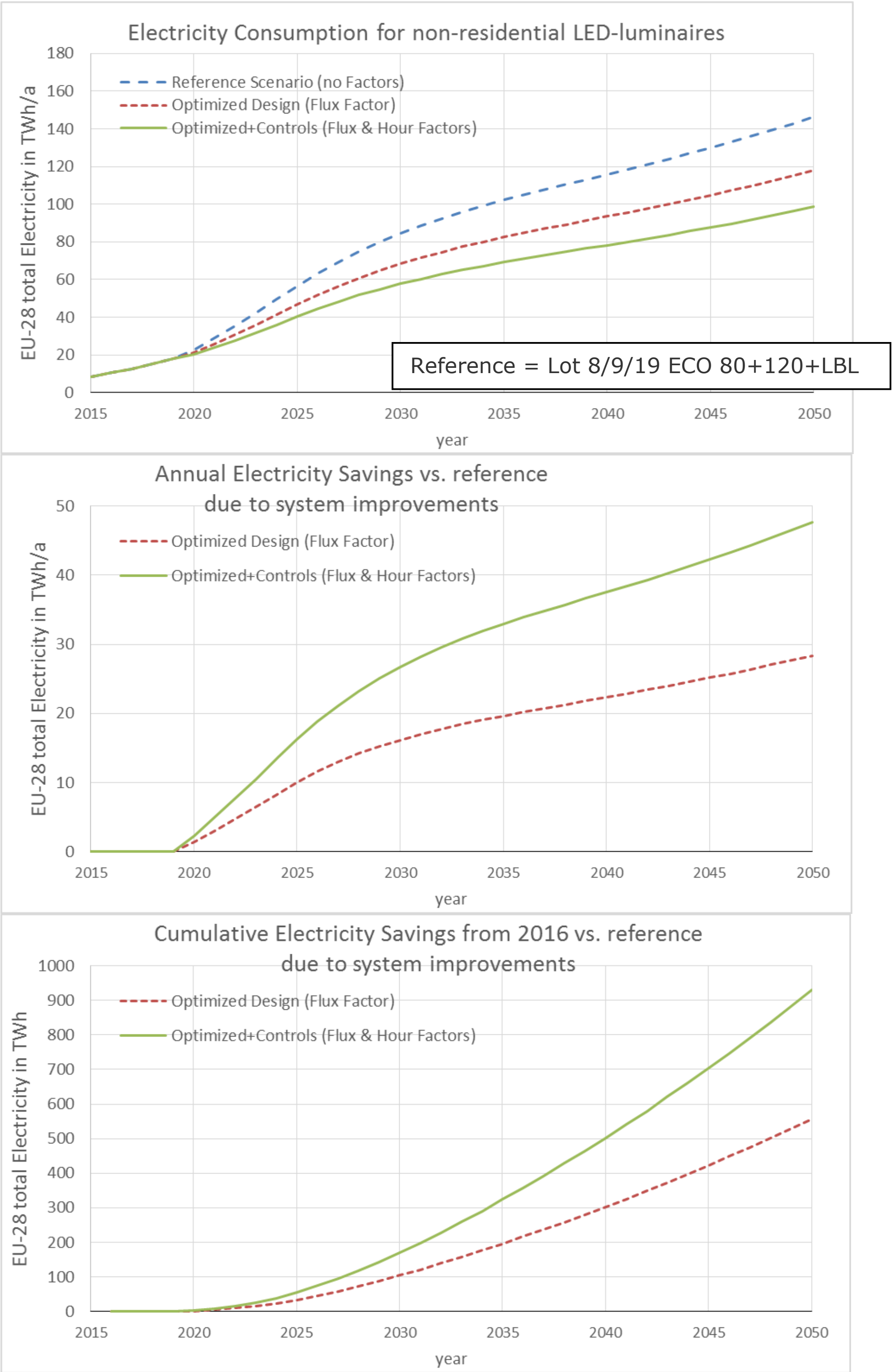


Figure 7-16 Electricity savings due to system improvements with respect to the Lot 8/9/19 ECO 80+120+LBL scenario (with labelling improvements)

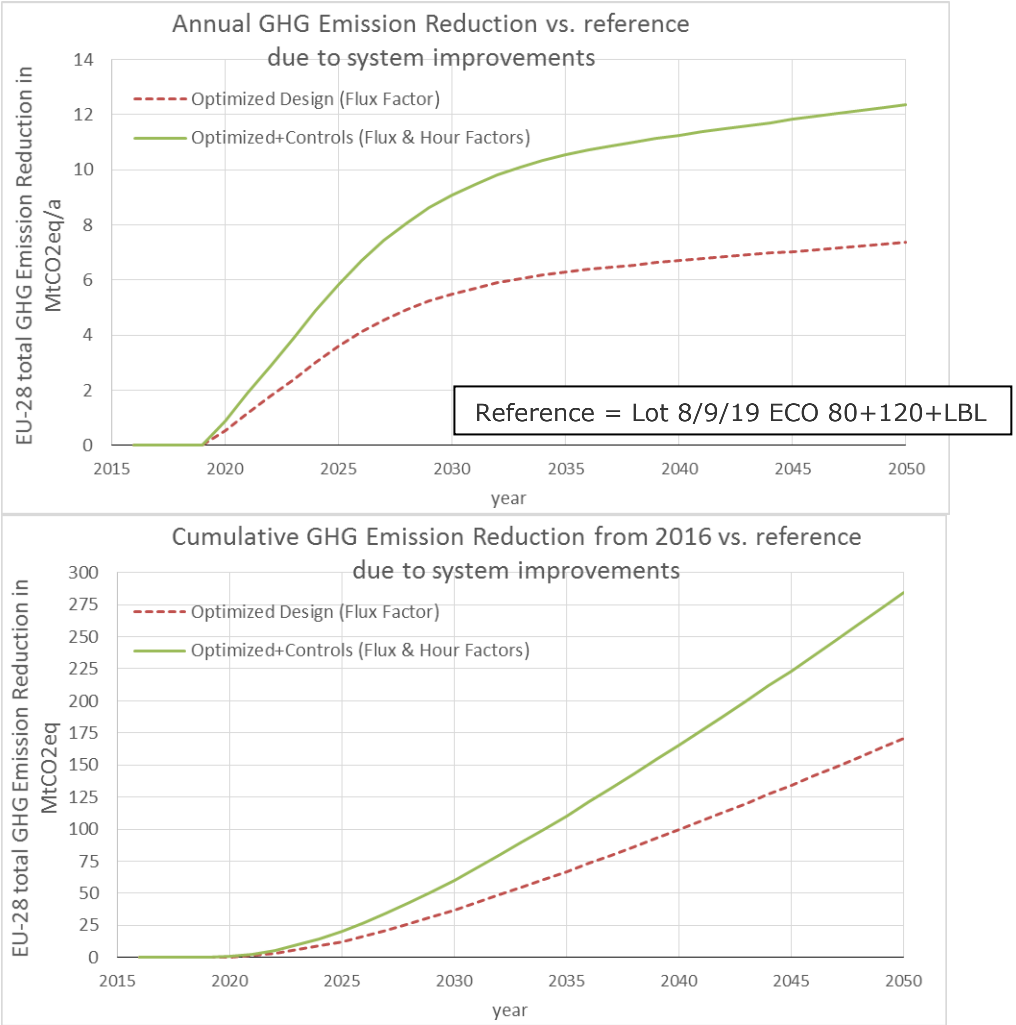


Figure 7-17 Greenhouse gas emission reduction in $MtCO_2eq$[254] due to system improvements with respect to the Lot 8/9/19 ECO 80+120+LBL scenario (with labelling improvements)

[254] $MtCO_2eq$ = Mega tonnes carbondioxide equivalent. Mt = 1 billion kilos. For comparison, the total EU-28 GHG emission is 4721 Mt CO_2 eq (source: EEA, GHG Inventory 2012. Total for EU-28 excl. land use, land-use change and forestry (LULUCF).)

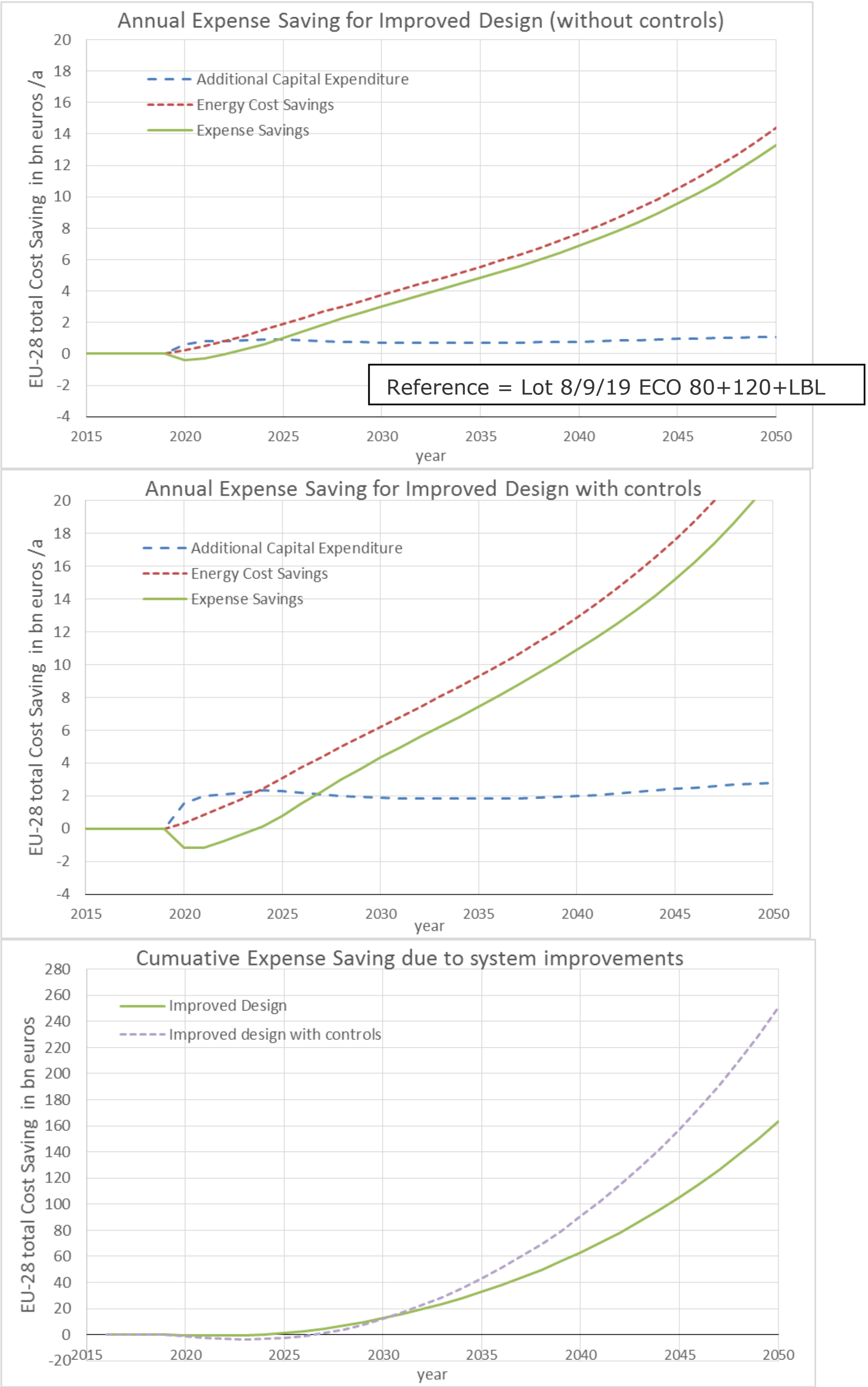


Figure 7-18 Cost savings due to system improvements with respect to the Lot 8/9/19 ECO 80+120+LBL scenario (with labelling improvements) (preliminary)

7.5.5 Impact Summary and Conclusions

Lighting system improvements have been expressed via the:

- Flux Factor F_{phi}, representing the average reduction in installed luminous flux at light source level due to system design optimisation, and
- Hour Factor F_{hour}, representing the average reduction in full-power equivalent annual operating hours due to implementation of lighting controls (switching on/off or dimming in function of daylight availability, room or road occupancy, or lumen degradation with time).

The electricity savings due to lighting system improvements have been estimated applying the factors F_{phi} and F_{hour} to the electricity consumption of integrated LED luminaires replacing LFL, CFLni or HID-luminaires in non-residential applications. This reference electricity consumption has been taken from the 'Model for European Light Sources Analysis' (MELISA) that was developed during the Lot 8/9/19 ecodesign preparatory study on light sources.

As future Ecodesign and energy labelling regulation for light sources is still under discussion (August 2016), the savings due to lighting system improvements have been computed for three different reference scenarios for light sources as defined in the Task 7 report of the Lot 8/9/19 study:

- BAU scenario (no new regulations on light sources),
- ECO 80+120 scenario (phase-out of all classical lighting technologies between 2020 and 2024; accelerated adoption of LEDs), and
- ECO 80+120+LBL scenario (same as previous but assuming additional energy labelling improvements; higher average efficacy for LEDs).

This approach guarantees that the savings computed for lighting systems are compatible with and complementary to those computed for light sources in the Lot 8/9/19 study, and that savings due to light source efficacy improvements are not counted twice. Note, however, that the proposed lighting design policy measures in section 7.2 can also contribute to achieving the proposed energy saving benefits from the ECO 80+120+LBL scenario, meaning that one has to select efficient light sources to achieve low LENI or AECI values.

Further, more robust impact estimates are only possible once new ecodesign and energy labelling regulations have been agreed on.

The computed electricity and GHG emission savings are expected to represent maximum possible (BAT) savings due to lighting system improvements.

The maximum EU-28 total savings for optimised lighting system designs without controls are presented in *Table 7-16* for the three reference light source scenarios. The optimised design (improved layout of luminaires in the space to be lit; choice of luminaires with higher light output efficacy) can be seen as a first step in lighting system improvement, satisfying relatively modest LENI or AECI ($kWh/m^2/a$) requirements. If luminaires would have been substituted anyway, the additional investment required has been estimated in a preliminarily manner as the design mark-up (+4 euros/m^2 indoor; +3% outdoor).

Depending on the reference scenario, EU-28 total annual electricity savings are 12-18 TWh/a in 2030 and 28-33 TWh/a in 2050. This is approximately 4% (2030) and 10% (2050) of total EU-28 lighting electricity consumption[255]. Cumulative electricity savings range between 68-113 TWh over the period 2020-2030, and 544-604 TWh over the period 2020-2050.

The EU-28 total annual reduction in GHG emissions ranges from 4-6 $MtCO_2eq$/a in 2030 and 7-9 $MtCO_2eq$ /a in 2050. This is approximately 0.1% of total EU-28 GHG emissions in 2012[248]. Cumulative emission reduction is 24-40 $MtCO_2eq$ over the period 2020-2030, and 163-185 $MtCO_2eq$ over the period 2020-2050.

The EU-28 total annual saving on user expenditure for lighting is 2-3 bn euros/a in 2030 and 13-15 bn euros/a in 2050. Savings in cumulative expenditure range from 9-14 bn euros over the period 2020-2030, and 160-180 bn euros over the period 2020-2050.

Table 7-16 Summary of EU-28 total savings due to an optimised lighting system design, with respect to different Lot 8/9/19 scenarios for light sources.

Impact Parameter	**Reference Scenario**	**2025**	**2030**	**2040**	**2050**
Reference Electricity (TWh/a)[1,2] for LED luminaires	BAU	36	62	121	173
	ECO 80+120	62	92	125	158
	ECO 80+120+LBL	57	84	116	146
Electricity for Optimised Design (TWh/a)	BAU	30	50	98	140
	ECO 80+120	51	74	101	128
	ECO 80+120+LBL	47	68	94	118
Annual Electricity Saving for Optimised Design (TWh/a)	BAU	6	12	24	33
	ECO 80+120	11	18	24	31
	ECO 80+120+LBL	10	16	22	28
Cumulative Electricity Saving for Optimised Design (TWh)	BAU	20	68	254	544
	ECO 80+120	37	113	328	604
	ECO 80+120+LBL	34	104	302	557
Annual GHG Emission Reduction for Optimised Design ($MtCO_2eq$/a)	BAU	2	4	7	9
	ECO 80+120	4	6	7	8
	ECO 80+120+LBL	4	6	7	7
Cumulative GHG Emission Reduction for Optimised Design ($MtCO_2eq$)	BAU	7	24	83	163
	ECO 80+120	14	40	108	185
	ECO 80+120+LBL	13	37	100	170
Annual User Expense Saving for Optimised Design (bn euros/a)	BAU	0.7	2.2	7.2	15.7
	ECO 80+120	1.2	3.4	7.5	14.5
	ECO 80+120+LBL	1.0	3.0	6.9	13.3
Cumulative User Expense Saving for Optimised Design (bn euros)	BAU	1.2	8.8	56	171
	ECO 80+120	2.0	14.7	71	181
	ECO 80+120+LBL	1.2	12.5	63	164

[255] BAU scenario, including also residential lighting, see *Table 7-10*: 275 TWh/a in 2030 and 291 TWh/a in 2050.

1: These data refer only to integrated LED luminaires substituting LFL, CFLni or HID-lamps in non-residential applications. Electricity for non-studied cases is included. The figures do not indicate the total electricity for non-residential lighting (see *Figure 7-6*).
2: Electricity includes the light source and the control gear. Electricity for lighting controls and for standby is not included. Special purpose applications are excluded.

The maximum EU-28 total savings for optimised lighting system designs with controls are presented in *Table 7-17* for the three reference light source scenarios. The addition of sensors and control devices allows switching on/off or dimming of lights as a function of daylight availability, room or road occupancy, or lumen degradation with time. The optimised design with controls can be seen as a second, advanced step in lighting system improvement, enabling the satisfaction of more stringent LENI or AECI ($kWh/m^2/a$) requirements. With respect to the optimised design without controls, additional costs for sensors and control devices are preliminarily estimated to be between 25 to 200 euros per luminaire, depending on the type of application.

Depending on the reference scenario, EU-28 total annual electricity savings are 20-29 TWh/a in 2030 and 48-56 TWh/a in 2050. This is approximately 9% (2030) and 18% (2050) of the total EU-28 electricity consumption for lighting[255]. Estimated cumulative electricity savings range from 110-180 TWh over the period 2020-2030, and from 900-1000 TWh over the period 2020-2050.

The EU-28 total annual reduction in GHG emissions is estimated to be 7-10 $MtCO_2eq/a$ in 2030 and 12-15 $MtCO_2eq$ /a in 2050. This is approximately 0.2% of total EU-28 GHG emissions in 2012[248]. Estimated cumulative emission reduction is 40-60 $MtCO_2eq$ over the period 2020-2030, and 270-300 $MtCO_2eq$ over the period 2020-2050.

The estimated EU-28 total annual saving in user expenditure for lighting ranges between 3-5 bn euros/a in 2030 and 21-25 bn euros/a in 2050. Estimated cumulative expenditure savings over the period 2020-2030 ranges from 9-16 bn euros, and from 250-280 bn euros over the period 2020-2050.

Table 7-17 Summary of EU-28 total savings due to an optimised lighting system design with controls, with respect to different Lot 8/9/19 scenarios for light sources.

Impact Parameter	**Reference Scenario**	**2025**	**2030**	**2040**	**2050**
Reference Electricity (TWh/a)[2,3] for LED luminaires	BAU	36	62	121	173
	ECO 80+120	62	92	125	158
	ECO 80+120+LBL	57	84	116	146
Electricity for Optimised Design +Controls (TWh/a)	BAU	26	42	82	117
	ECO 80+120	44	63	85	107
	ECO 80+120+LBL	41	58	78	99
Annual Electricity Saving for Optimised Design +Controls (TWh/a)	BAU	10	20	39	56
	ECO 80+120	18	29	41	52
	ECO 80+120+LBL	16	27	38	48
Cumulative Electricity Saving for Optimised Design +Controls (TWh)	BAU	32	109	417	904
	ECO 80+120	60	185	545	1009
	ECO 80+120+LBL	55	170	502	931
Annual GHG Emission Reduction, Optim. Design +Controls ($MtCO_2eq/a$)	BAU	3	7	12	15
	ECO 80+120	6	10	12	13
	ECO 80+120+LBL	6	9	11	12

Cumulative GHG Emission Reduction for Optim. Design +Controls ($MtCO_2eq$)	BAU	12	38	136	271
	ECO 80+120	22	65	180	308
	ECO 80+120+LBL	20	60	165	284
Annual User Expense Saving for Optim. Design +Controls (bn euros/a)	BAU	0.6	2.9	11.3	25.5
	ECO 80+120	1.2	4.9	12.0	23.5
	ECO 80+120+LBL	0.8	4.3	10.9	21.4
Cumulative User Expense Saving for Optim. Design +Controls (bn euros)[3]	BAU	-0.1	9.3	80	265
	ECO 80+120	-1.1	16.3	104	280
	ECO 80+120+LBL	-2.6	12.2	90	251

1: These data refer only to integrated LED luminaires substituting LFL, CFLni or HID-lamps in non-residential applications. Electricity for non-studied cases is included. The figures do not indicate the total electricity for non-residential lighting (see *Figure 7-6*).
2: Electricity includes the light source and the control gear. Electricity for lighting controls and for standby is not included. Special purpose applications are excluded.
3: A negative saving indicates an additional expense. Capital Expenditure data and User Expense data are preliminary (further study recommended)

Further savings, against low additional costs, are possible by improving the reflectance of indoor surfaces, see section 7.5.2-7.5.4.

7.6 Sensitivity analysis

Objective:
In a complete Ecodesign preparatory study the analysis in this section should investigate the sensitivity of the main outcomes for changes in the main calculation parameters. This sensitivity analysis is performed at scenario level. The sensitivity analysis in Task 6 is performed at base case level.
This sensitivity analysis should also serve to compensate for weaknesses in the robustness of the reference scenarios and policy options due to uncertainties in the underlying data and assumptions.

For the present study this analysis cannot be performed because the required technical and economic data from Tasks 5&6 are unavailable.