



BSI Standards Publication

Energy performance of buildings — Energy requirements for lighting

Part 2: Explanation and justification of
EN 15193-1, Module M9

National foreword

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**Energy performance of buildings - Energy requirements
for lighting - Part 2: Explanation and justification of EN
15193-1, Module M9**

Performance énergétique des bâtiments - Exigences
énergétiques pour l'éclairage - Partie 2: Explication et
justification de l'EN 15193-1, Module M9

Energetische Bewertung von Gebäuden - Energetische
Anforderungen an die Beleuchtung - Teil 2:
Technischer Bericht zu EN 15193-1

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European foreword

This document (CEN/TR 15193-2:2017) has been prepared by Technical Committee CEN/TC 169 "Light and lighting", the secretariat of which is held by DIN.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been prepared by the Working Group CEN/TC169/WG 9 "Energy performance of buildings".

The document layout is structured to largely follow the content of the standard EN 15193-1:2017.

EN 15193 consists of the following parts, under the general title "Energy performance of buildings — Energy requirements for lighting"

- Part 1: Specifications, Module M9
- Part 2: (Technical Report) Explanation and justification of EN 15193-1, Module M9

Directive 2010/31/EU recasting the Directive 2002/91/EC on energy performance of buildings (EPBD, [EF4] [4]) promotes the improvement of the energy performance of buildings within the European Union, taking into account all types of energy uses (heating, lighting, cooling, air conditioning, ventilation) and outdoor climatic and local conditions, as well as indoor climate requirements and cost effectiveness (Article 1).

The directive requires Member States to adopt measures and tools to achieve the prudent and rational use of energy resources. In order to achieve those goals, the EPBD requires increasing energy efficiency and the enhanced use of renewable energies in both new and existing buildings. One tool for this is the application by Member States of minimum requirements on the energy performance of new buildings and for existing buildings that are subject to major renovation, as well as for minimum performance requirements for the building envelope if energy-relevant parts are replaced or retrofitted. Other tools are energy certification of buildings, inspection of boilers and air-conditioning systems.

The use of European Standards increases the accessibility, transparency and objectivity of the energy performance assessment in the Member States facilitating the comparison of best practices and supporting the internal market for construction products. The use of EPB-standards for calculating energy performance, as well as for energy performance certification and the inspection of heating systems and boilers, ventilation and air-conditioning systems will reduce costs compared to developing different standards at national level.

The first mandate to CEN to develop a set of CEN EPBD standards (M 343, [EF1] [1]), to support the first edition of the EPBD ([EF2] [2]) resulted in the successful publication of all EPBD related CEN standards in 2007-2008.

The mandate M 480 was issued to review the mandate M 343 as the recast of the EPBD raised the need to revisit the standards and reformulate and add standards so that they become on the one hand unambiguous and compatible, and on the other hand a clear and explicit overview of the choices, boundary conditions and input data that need to be defined at national or regional level. Such national

or regional choices remain necessary, due to differences in climate, culture and building tradition, policy and legal frameworks. Consequently, the set of CEN-EPBD standards published in 2007-2008 had to be improved and expanded on the basis of the recast of the EPBD.

The EPB standards are flexible enough to allow for necessary national and regional differentiation and facilitate Member States implementation and the setting of requirements by the Member States.

Further target groups are users of the voluntary common European Union certification scheme for the energy performance of non-residential buildings (EPBD art.11.9) and any other regional (e.g. Pan European) parties wanting to motivate their assumptions by classifying the building energy performance for a dedicated building stock.

Introduction

The set of EPB standards, technical reports and supporting tools

In order to facilitate the necessary overall consistency and coherence, in terminology, approach, input/output relations and formats, for the whole set of EPB-standards, the following documents and tools are available:

- a) a document with basic principles to be followed in drafting EPB-standards: CEN/TS 16628:2014, Energy Performance of Buildings - Basic Principles for the set of EPB standards [5];
- b) a document with detailed technical rules to be followed in drafting EPB-standards: CEN/TS 16629:2014, Energy Performance of Buildings - Detailed Technical Rules for the set of EPB-standards [6];
- c) the detailed technical rules are the basis for the following tools:
 - 1) a common template for each EPB-standard, including specific drafting instructions for the relevant clauses;
 - 2) a common template for each technical report that accompanies an EPB standard or a cluster of EPB standards, including specific drafting instructions for the relevant clauses;
 - 3) a common template for the spreadsheet that accompanies each EPB standard, to demonstrate the correctness of the EPB calculation procedures.

Each EPB-standards follows the basic principles and the detailed technical rules and relates to the overarching EPB-standard, EN ISO 52000-1:2017.

One of the main purposes of the revision of the EPB-standards is to enable that laws and regulations directly refer to the EPB-standards and make compliance with them compulsory. This requires that the set of EPB-standards consists of a systematic, clear, comprehensive and unambiguous set of energy performance procedures. The number of options provided is kept as low as possible, taking into account national and regional differences in climate, culture and building tradition, policy and legal frameworks (subsidiarity principle). For each option, an informative default option is provided (Annex B).

Rationale behind the EPB technical reports

There is a risk that the purpose and limitations of the EPB standards will be misunderstood, unless the background and context to their contents – and the thinking behind them – is explained in some detail to readers of the standards. Consequently, various types of informative contents are recorded and made available for users to properly understand, apply and nationally or regionally implement the EPB standards.

If this explanation would have been attempted in the standards themselves, the result is likely to be confusing and cumbersome, especially if the standards are implemented or referenced in national or regional building codes.

Therefore each EPB standard is accompanied by an informative technical report, like this one, where all informative content is collected, to ensure a clear separation between normative and informative contents (see CEN/TS 16629 [6]):

- to avoid flooding and confusing the actual normative part with informative content,
- to reduce the page count of the actual standard, and

— to facilitate understanding of the set of EPB standards.

This was also one of the main recommendations from the European CENSE project [8] that laid the foundation for the preparation of the set of EPB standards.

This Technical Report

This Technical Report accompanies the standard EN 15193-1:2017 on energy requirements for lighting in buildings. The role and the positioning of the accompanied standard in the set of EPB standards is defined in the Introduction to the standard.

All buildings occupied by humans require lighting indoors so that people have satisfactory visibility to move around and be able to participate in activities and carry out visual tasks. The lighting conditions required vary for different buildings, activities and visual tasks and these are well defined in the CEN lighting application standards EN 12464-1 for indoor work places, EN 12193 for sports facilities and EN 1838 for emergency lighting. As yet there are no CEN standards for lighting of domestic buildings but this document gives some guidance on requirements and solutions in Annex N.

It is very important that all occupied buildings or places have the right lighting conditions and that this lighting is provided by energy efficient solutions. Such solutions can be achieved with electric light or daylight or a combination of the two and are managed by appropriate lighting controls. The correct lighting solution for all buildings or places is established by comprehensive lighting design process. As yet there are no standards defining the lighting design process and the lighting design process is not part of this document. However, this Technical Report provides a general overview of the processes involved in interior lighting design as illustrated in Figure 1. Making comprehensive lighting design for new or refurbished buildings can yield effective and energy efficient lighting solutions that fulfil all the lighting criteria specified in the appropriate lighting application standards.

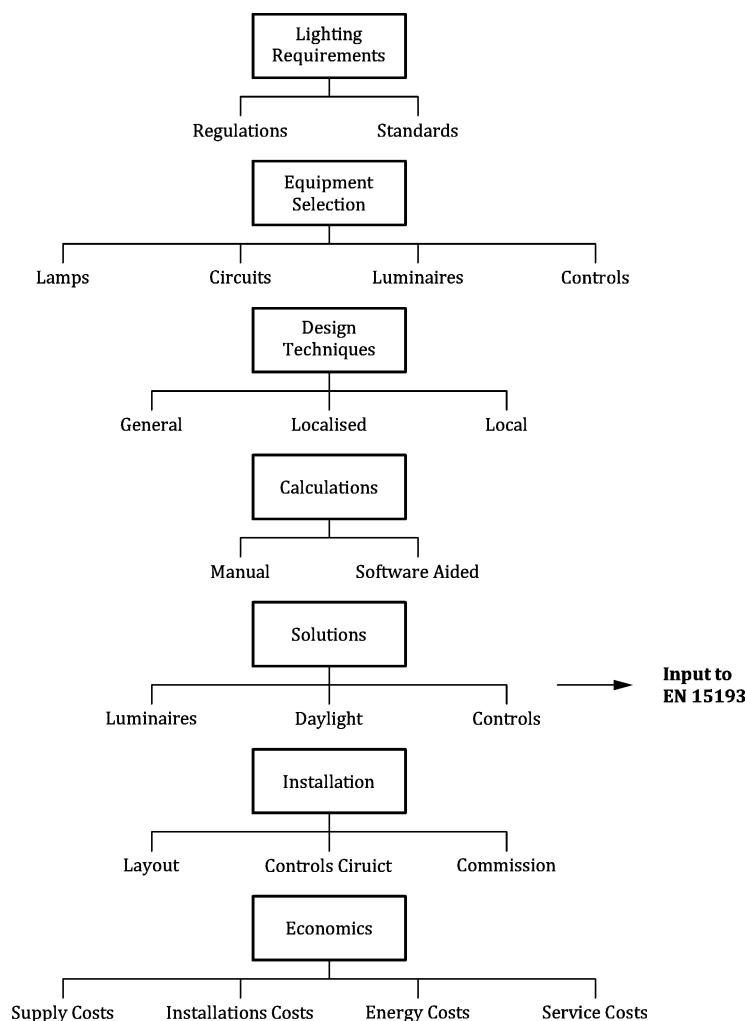


Figure 1 — General overview of the comprehensive lighting design process

The lighting design will include lighting controls that maybe passive (operated manually) or active (automatically controlled) or a combination of the two systems. The lighting controls can be an integral part of the lighting system and the power required for operation is included in the estimation of the energy requirements for lighting. However, the lighting control can be independent of the lighting system and the power needed for these is not included in the estimation of the energy required for lighting.

There might be requirements to provide lighting outside the building such as pathway lights to assist visibility for safe movement and security lighting around the perimeter for the protection of the buildings, and lighting of outdoor workplaces see EN 12464-2:2014. Floodlighting to beautify the façade or entrance at night can also be added. These lighting systems are described in Annex O. The energy for these outdoor lighting systems can be supplied from the building but they are not included in the calculation of the energy requirements for lighting in the building.

Accompanying spreadsheet(s)

Concerning the accompanied standard EN 15193-1:2017 a spreadsheet was produced. In this Technical Report, examples of the calculations are included.

1 Scope

This Technical Report is accompanying the lighting standard EN 15193-1:2017 and gives information to support the correct understanding, use and national implementation of this lighting standard.

This document provides:

- commentary to clauses of the standard;
- explanation on the procedures and gives background information;
- justification of the choices that have been made;
- description of the processes;
- spreadsheet of the calculation process;
- worked examples and benchmark values;
- advice on lighting control systems; and
- guidance on the lighting design for domestic buildings.

This document discusses but does not formally detail the lighting design process.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

EN 15193-1:2017, *Energy performance of buildings - Energy requirements for lighting - Part 1: Specifications, Module M9*

EN ISO 52000-1:2017, *Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures (ISO 52000-1:2017)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 52000-1:2017, EN 15193-1:2017, EN 12665 and the following apply.

3.1 circuit

electrical network composed of components connected by conductive wires through which electric current can flow and perform various operations

3.2 general lighting

substantially uniform lighting of an area without provision for special local requirements

3.3

localized lighting

lighting designed to illuminate an area with a higher illuminance at certain specified positions, for instance those at which work is carried out

3.4

local lighting

lighting for a specific visual task, additional to and controlled separately from the general lighting

3.5

useful area

A

area of the building normally occupied or used and is being considered (unit: m²)

4 Symbols and abbreviations

4.1 Symbols

For the purposes of this document, the symbols given in EN ISO 52000-1:2017, EN 15193-1:2017 and the specific symbols listed in Table 1 apply.

Table 1 — Symbols and units

A_{Ca}	Area of the raw building carcass opening of the area under consideration	m ²
A_D	Partial area which is lit by daylight	m ²
a_D	Depth of the daylight area	m
$a_{D,max}$	Maximum depth of the daylight area	m
A_{Dj}	Area receiving daylight	m ²
A_{FS}	Glazed area of a dome or strip skylight	m ²
$a_{In,At}$	Depth of the courtyard or atrium	m
A_{ND}	The area not lit by daylight	m ²
A_{NDj}	Area not receiving daylight	m ²
A_{Rb}	Glazed area of a shed rooflight	m ²
A_S	Sum of task areas within the room	m ²
b_D	Width of the daylight area	m
$b_{In,At}$	Width of the courtyard or atrium	m
C_{we}	Factor for reduction to take account of weekends	-
D	Daylight factor	%
D_a	External daylight factor	%
$D_{AC,j}$	Daylight factor for raw carcass opening	%
D_{CA}	Daylight factor from carcass opening	%
D_{class}	Classification of daylight availability	-
$\bar{D}_{SA}$	Mean daylight factor with rooflight, shading activated	%
$\bar{D}_{SNA}$	Mean daylight factor with rooflight, shading not activated	%

E_A	Horizontal external illuminance from an overcast sky	lx
E_F	Illuminance on the external surface of the skylight from overcast sky	lx
e_L	Expenditure factor for lighting systems	-
$e_{L,C}$	Partial expenditure factor for constant illuminance control	-
$e_{L,D}$	Partial expenditure factor for daylight dependant lighting control	-
$e_{L,ES}$	Partial expenditure factor for the electric lighting system	-
$e_{L,ES,del}$	Partial expenditure factor for delivery of electric light	-
$e_{L,ES,dis}$	Partial expenditure factor for distribution of electric light	-
$e_{L,ES,gen}$	Partial expenditure factor for generation of electric light	-
$e_{L,O}$	Partial expenditure factor for occupancy dependant lighting control	-
$\bar{E}_m$	Maintained illuminance	lx
E_{SUR}	Maintained illuminance on immediate surround of task area	lx
E_{task}	Maintained illuminance on the task area	lx
F	Dependency Factor	-
F_A	Absence factor	-
f_B	The efficiency of the operating device	-
F_c	Constant illuminance factor	-
F_{CA}	Factor for reduced power of area	-
F_{cc}	Factor for the efficiency of the constant illuminance control	-
F_{COD}	Factor for the over design of the illuminance by using more luminaires to suit the required layout	
F_D	Daylight dependency factor	-
$F_{D,C}$	Lighting control factor	-
$F_{D,C,nj}$	Daylight responsive control system factor for the area under consideration	-
$F_{D,j,i}$	Factor for monthly partial-load daylight operation	-
$F_{D,mth}$	Monthly daylight dependency factor	-
$F_{D,n,j}$	Daylight dependency factor for the area under consideration	-
$F_{D,S}$	Daylight supply factor	-
$F_{D,S,j}$	Daylight supply factor for a vertical façade	-
$F_{D,S,nj}$	Daylight supply factor for the area under consideration	-
$F_{D,S,SA,j}$	Daylight supply factor of the area when solar or glare protection system is activated	-
$F_{D,S,SNA,j}$	Daylight supply factor of the area for when solar or glare protection system is not activated	-
F_L	Factor for equipment efficiency	-
F_{MF}	Correction factor for MF	-
F_o	Occupancy dependency factor	-
F_{oc}	Controls function factor	-

F_u	Utilization factor of the luminaire	-
F_{ue}	Utilization factor for determination of the energy use	-
H_{dir}	Luminous exposure from direct insolation	lx s
H_{dir} / H_{glob}	Ratio for climate characterization	-
H_{glob}	Luminous exposure from global insolation	Lx s
h_{Li}	Height of the window lintel above the floor	m
$h_{lm,At}$	Height of the courtyard or atrium from floor level to the roof level	m
h_m	Mounting height of luminaire	m
h_R	Distance between workplane and ceiling	m
h_{Rj}	Distance between floor and ceiling height in an area with roof lights	m
h_{Ta}	Height of the task area above the floor.	m
$I_{RD,j}$	Space depth index of the area under consideration	-
$I_{Sh,GDF}$	Correction factor for glazed double façades of the area under consideration	-
$I_{Sh,hA}$	Correction factor for overhang shading of the area under consideration	-
$I_{Sh,j}$	Shading index of the area under consideration	-
$I_{Sh,lsh}$	Correction factor for linear obstruction of the area under consideration	-
$I_{Sh,ln,At}$	Correction factor for internal courtyard and atrium shading of the area under consideration	-
$I_{Sh,vA}$	Correction factor for side shading of the area under consideration	-
$I_{Sh,vf}$	Correction factor for vertical projection	-
$I_{Tr,j}$	Transparency index in the area under consideration	-
J_i	Day of the month	-
K	Room Index	-
k_1	Reduction factor for the frames or subdivisions	-
k_2	Reduction factor for pollution of the glazing	-
k_3	Reduction factor of non-vertical light incident upon the glazing	-
$k_{obl,1}$	Reduction factor for the frames or subdivisions in rooflights	-
$k_{obl,2}$	Reduction factor by pollution of the glazing of rooflights	-
$k_{obl,3}$	Reduction factor for non-vertical light incidence on the rooflight glazing	-
$k_{Sh,GDF,1}$	Reduction factor for the frames or subdivisions in a double glazed façade	-
$k_{Sh,GDF,2}$	Reduction factor by pollution of the glazing of the double glazed façade	-
$k_{Sh,GDF,3}$	Reduction factor for non-vertical light incidence on the façade glazing	-
$k_{Sh,ln,At,1}$	Reduction factor for the frames or subdivisions in the atrium façade	-
$k_{Sh,ln,At,2}$	Reduction factor by pollution of the glazing of the atrium façade	-

$k_{Sh,ln,At,3}$	Reduction factor for non-vertical light incidence of the atrium façade	-
L_{80}	time period at which x % of the measured initial luminous flux value is maintained	-
L_R	Length of room	m
N_i	Number days in the respective month	d
P_{ci}	Luminaire control standby power	W
p_e	Electrical evaluation power for determination of the energy use	W
P_{ei}	Luminaire emergency standby power	W
P_{em}	Total emergency standby power	W
P_i	Luminaire power	W
P_j	Power density of the area	W/m ²
$P_{j,lx}$	Power density per lux	W/lm
P_{max}	Maximum luminaire power with value taken at the end of the luminaire light source maintenance cycle	W
P_{min}	Minimum luminaire power with value taken at the start of the luminaire light source maintenance cycle	W
P_n	Total power of n number of luminaires	W
P_{pc}	Total controls standby power	W
$t_{as,i}$	Time usage after sunset	h
$t_{bs,i}$	Time usage before sunrise	h
t_D	Daylight time	h
t_{Day}	Monthly daylight time hours	h
$t_{Day,nj}$	Daylight time for the area under consideration	h
t_e	Battery charge time only	h
$t_{eff,Day,nj}$	Daylight effective time for the area under consideration	h
$t_{end,i}$	Time at the end of usage	Real time in h
t_{eq}	Time difference between apparent solar time and mean solar time (equation of time)	h
t_N	Daylight absence time	h
t_{Night}	Monthly night time hours	h
$t_{rel,D,SA,j}$	The relative portion of the total operating time during which the solar or glare protection system is activated	h
$t_{rel,D,SNA,j}$	The relative portion of the total operating time during which the solar or glare protection system is not activated	h
t_s	Time step	Hour / month / year
t_{SA}	Time when solar or glare protection is activated	h
t_{SNA}	Time when solar or glare protection is not activate	h
$t_{start,i}$	Time of the beginning of usage	Real time in h
$t_{sunrise,i}$	Sunrise time	Real time in h
$t_{sunset,i}$	Sunset time	Real time in h

t_{tot}	Total operating hours	h
t_y	Number of hours in a standard year	h
$v_{month,j}$	Factor for monthly distribution	-
W_{az}	Annual energy required for lighting for an area or zone	kWh/year
w_i	Well index	-
$W_{L,t}$	Total energy for illumination	kWh
W_{mt}	Metered energy	kWh
W_{nd}	Energy needed for lighting	kWh
W_{pc}	Standby energy density for automatic lighting controls of the luminaire per year	kWh/m ² year
W_{pe}	Standby energy density for battery charging of emergency luminaires per year	kWh/m ² year
$W_{P,t}$	Total energy for standby	kWh/ t_s
w_R	Width of room	m
W_t	Energy per time step	W / t_s
W_{US}	Energy used for lighting	kWh
γ	Latitude angle	degrees
$\gamma_{Sh,lsh}$	Obstruction altitude angle	degrees
$\gamma_{Sh,hf}$	Horizontal shading angle due to horizontal projection	degrees
$\gamma_{Sh,vf}$	Vertical shading angle due to vertical projection	degrees
δ	Declination of the sun	Degrees
$\Delta F_{D,S,j}$	Difference of daylight supply factor	
η_L	Lamp (light source) luminous efficacy	lm/W
η_{LB}	Luminaire light output ratio	-
η_R	Utilance	-
ρ_C	Reflectance of ceiling	-
ρ_F	Reflectance of floor	-
ρ_W	Reflectance of walls	-
$\tau_{D65,SA}$	Transmittance of diffuse rooflight glazing with shading activated	-
$\tau_{D65,SNA}$	Transmittance of the façade glazing for vertical incident light	-
τ_{eff}	Effective transmittance	-
$\tau_{eff,SNA,j}$	Effective transmittance of the façade glazing when solar or glare protection system is not activated	-
$\tau_{Sh,GDF,D65}$	Transmittance of the external layer of glazing of the double glazed façade	-
$\tau_{Sh,ln,At,D65}$	Transmittance of the atrium glazing	-
Φ	Latitude	degrees
ω_i	Hour angle	degrees

4.2 Subscripts

For the purposes of this document, the subscripts given in EN ISO 52000-1:2017, EN 15193-1:2017 and the specific symbols listed in Table 2 apply.

Table 2 — Subscripts

L	lighting	an	annual	m	monthly
occ	occupied period				

4.3 Abbreviations

For the purposes of this document, the abbreviations given in EN ISO 52000-1:2017, EN 15193-1:2017 and the specific symbols listed in Table 3 apply.

Table 3 — Abbreviations

BMS	Building Management System	-
CFL	Compact Fluorescent Lamp	-
LED	Light Emitting Diode	-
T16	16 mm diameter linear fluorescent tube	-
T26	26 mm diameter linear fluorescent tube	-
TH	Tungsten Halogen lamp	-
CFS	Complex Fenestration Systems	-
SP	System Potential	-
CLO	Constant Lumen Output	-
PIR	Passive Infrared Sensor	-
PE	Photo Electric cell sensor	-
DALI	Digital Addressable Lighting Interface	-
PC	Personal Computer	-
CAD	Computer Aided Design	-
N	North	-
E	East	-
S	South	-
W	West	-

5 Brief description of the method(s) and routing

5.1 General

The standard gives three methods for the assessment of the energy required for electric lighting within buildings in the residential and non-residential lighting sectors. There are two methods for the estimation by calculations and one by direct metering of the energy for lighting. Figure 2 illustrates the general flow of the assessment process. The calculation methods can be used during feasibility study or detailed design of new or refurbished buildings and for the assessment of energy use in existing buildings. The metered method can only be used in existing buildings that have segregated lighting circuits that includes meters to facilitate direct metering of the energy used for lighting only or a building management system that can measure energy use by lighting. The metering by BMS (Building Management System) or other remotely managed smart systems are not covered by this Technical Report but examples of direct metering of lighting circuits are given in 8.6.1. The calculations method can be applied to existing buildings by first performing a lighting installation audit.

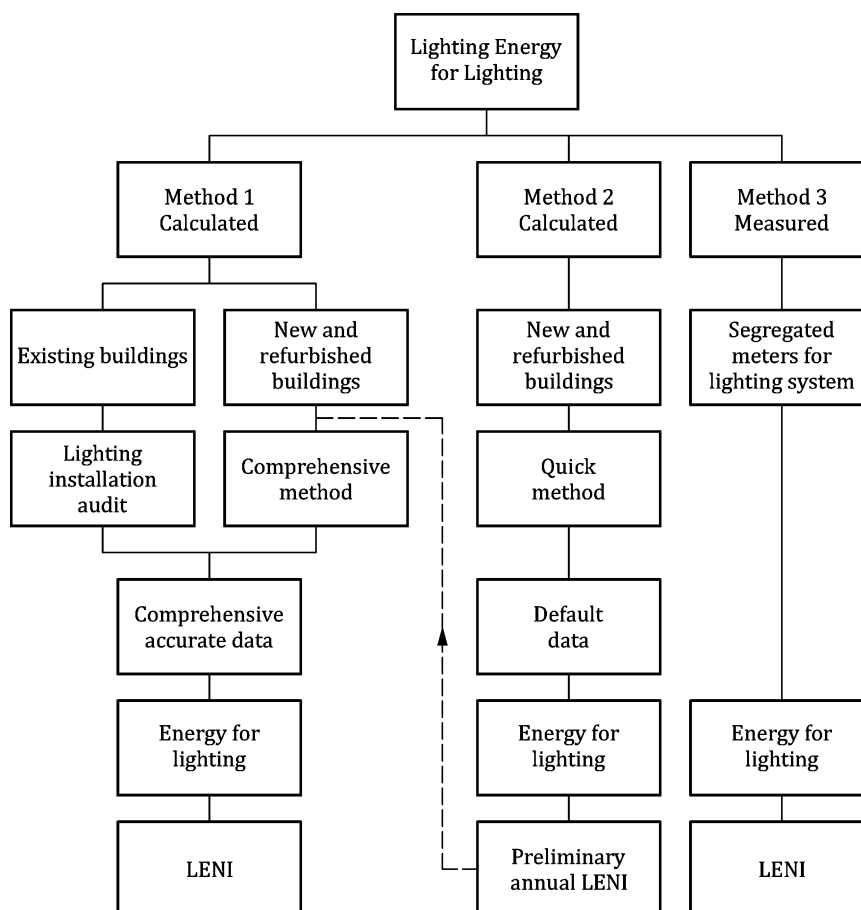


Figure 2 — Overview of the flow of the process to determine the required energy for lighting and LENI, the indicator of the energy efficiency of the lighting, in buildings

The methods described will yield the electric energy required for lighting in the selected time steps and can provide the Lighting Energy Numeric Indicator (LENI) for the building, room or zones. LENI can be used for comparison of similar buildings and also as a measure of the lighting energy performance of the building.

This document provides examples for calculation checks and assistance in the development of calculation software tool with the aid of a suitable spread sheet. The spread sheet will show the data needs and calculation process and can be used for validation.

For new and refurbished buildings there are two calculation methods. The first 'Method 1' is the preferred route that follows a comprehensive procedure and the second 'Method 2' is a simplified quick method for the lighting energy estimation.

Method 1 assumes that for the building a comprehensive lighting system design has been performed. The lighting system design produced the required lighting scheme and was based on real data of the specified products. The scheme and product information provides the input to the lighting energy estimation process. For existing buildings the process involves making an audit of the lighting scheme to establish the installed lighting load. Method 1 is the most accurate calculation method.

Method 2 is a quick method making use of default data in the approximation procedure to calculate the budget installed load and the energy requirement for lighting.

Method 3 is by metering and will give the most accurate measure of the energy used for lighting.

For the indication of the lighting energy efficiency in the buildings LENI offers a valuable measure. LENI (the Lighting Energy Numeric Indicator) is a simple concept and gives a very good comparative

measure for the lighting energy efficiency performance of buildings. The measure can be used for comparing the performance of similar building types in the EU. The measure can also offer the opportunity to set lighting efficiency ratings or benchmarks for designers of lighting solutions. LENI has been in use since 2007 and several EU member states have adopted it as the tool for setting lighting efficiency measures in buildings.

5.2 Selection criteria

The standard offers calculation methods, with different levels of accuracy for the installed power, occupancy estimation and daylight availability and these should be considered when making the method selection. In this process the available input data will also restrict the choice in the method.

Method 1 provides the most accurate calculation procedure and it relies upon a comprehensive lighting scheme design as the main input to the energy calculation.

Method 2 provides a quick estimation aimed for pre-design calculations and employs default values. Default values are provided in Annex B of the standard but these may be substituted by national defined values for which templates are provided in Annex A in the standard.

Method 3 provides the most accurate energy use for lighting information but can only be used after the building has been commissioned and occupied. This method can also be linked to the BMS of the building to provide continuous smart metering.

NOTE For the correct use of this standard the choices between methods will preferably be made according to the available data and the accuracy required. Default data template is necessary but not enough to guarantee consistency of the data. The chosen method in particular for the application within the context of EU Directives may be transposed into national legal requirements.

6 Method 1 – Calculation of the energy required for lighting

6.1 Rationale

Method 1 is a comprehensive method that assumes that for the building a comprehensive lighting system design has been performed. The lighting system design produced the required lighting scheme and was based on real data of the specified products. The scheme and product information provides the input to the lighting energy estimation process. The method is suitable for new or for refurbishment of existing buildings. For existing buildings the process involves making an audit of the lighting scheme to establish the installed lighting load.

6.2 Time steps

The time steps for calculations are harmonized across all EPB related standards. In this Technical Report the time steps are:

Yearly, assuming average 8 760 h.

Monthly, assuming average 730 h.

The provided method for the estimation of the lighting energy demand is based on an annual approach (see Annex F on day lighting). Seasonal impacts can be regarded by monthly correction factors. Hourly values cannot be derived in any correct correlation with climatic data. Accurate hourly calculation of the energy required for lighting is not practical as there is no robust method for the prediction of the values of the dependency factors. However, Annex P gives an approximate method for the hourly intervals of estimating the energy required or used by lighting. This method should provide hourly data for the energy balance of heating and cooling load estimations of the place or building. The only way to achieve a degree of accuracy in the estimation of daylight supply is by using standard detailed lighting simulation method referred to in F.8, but this method is not within the scope of the standard and technical report.

An alternative and simpler way to, at least formally, link into the hourly calculation scheme of other parts of the energy balance, such as internal loads for heat load calculation, is by the average hourly value. The average hourly value may be obtained from the monthly calculated value divided by the hours in the month. For each month a constant (not variable) term will therefore be added as lighting energy to the other hourly variable parts of the energy balance.

The reason for this restriction lies in modelling the impact of daylight. This requires a photometrical correct three dimensional calculation scheme of the light distribution outside entering through the facades into the adjacent indoor spaces. Early simple approaches have been based on the determination of the daylight factor (D) at a given inside position and an hourly multiplication with an estimate of the outside illuminance in order to obtain the indoor natural illumination which can then serve as basis for estimating the electric lighting needs. As the daylight factor is defined for a CIE overcast sky only (fixed uncommon outside luminance distribution), multiplication of the daylight factor with general outside illuminance values as derived from real weather data (including clear, sunny and partially overcast conditions) led to significant and not tolerable errors. Moreover the daylight factor method does not allow accounting for any sun shading devices, which are mandatory in today's rating methods. Simplified methods to cope on an hourly basis - without the use of photometric algorithms - with the versatile outside luminance distribution and complex light transmission through façade elements like different sun-shading systems so far do not exist.

Therefore rating the impact of daylight nowadays has been accounted for in such a way, that monthly and annual detailed simulation runs with photometrical exact sky and room models have been performed with lighting simulation software for a representative set of room geometries, sun-shading devices and locations. From this detailed simulation results, regression models (analytical and tabular) have been derived, allowing to estimate the annual and monthly impact of daylight penetration through the façade without the need of using detailed computer tools, with a higher accuracy than the former D (Daylight Factor) method and allowing to incorporate not only simple glazing systems but also sun-shading and light redirection devices.

Generally speaking, selecting a calculation step that is smaller than necessary makes application more complicated than necessary as the occupation profiles and other input parameters needed for hourly calculation are considerably more detailed. As monthly or even annual balancing methods can be sufficiently precise for all balancing applications a monthly balancing procedure should be chosen in order to improve the acceptance and user-friendliness of the standard.

Nevertheless, if deemed necessary the direct usage of detailed lighting simulation software on an hourly basis is always possible (see F.8) at then of course higher expenses (modelling and calculation time).

No reliable method can be recommended to break down the monthly period values to hourly time steps. This implies that the overall general hourly method cannot properly represent energy flows in the building on hourly time steps.

6.3 Assumptions

A comprehensive lighting scheme has been designed including controls with protocols. The scheme fully meets the lighting requirements specified in the lighting application standards.

6.4 Data input

6.4.1 General

For most new or refurbished buildings it is assumed that the required lighting solution will be established by performing a comprehensive lighting system design. The lighting design process is not part of this Technical Report but an overview of the main considerations in the design process is shown in Figure 1. The lighting design criteria may be obtained from the standards for workplaces in EN 12464-1, for sport places in EN 12193 and for domestic places in Annex N of this Technical Report. The completion of the lighting design process will produce the lighting solution, the required lighting

scheme and the product schedule. The lighting solution will give details of the required luminaire types and the lighting control system. There may be several types of luminaires in the scheme each performing specific functions from a specific mounting position. The luminaire types may only be used for illumination but some may also contain components to provide emergency lighting. The luminaires usually have embodied components to make them controllable and dimmable by receiving signals from detectors mounted remotely but powered by the luminaire or they may even be self-managed by inbuilt detectors. Each luminaire type will have a unique product reference code as described in EN 12665 for identification provided by the manufacturer.

6.4.2 New or refurbished building lighting system data

The information and data on the type and number of luminaires used in a zone, room or building and the type of controls is required to form the input data for the estimation procedure of the energy requirements for lighting. An example of how the lighting system data may be set out is shown in Table 4.

Table 4 — Example schedule of the luminaires in the lighting scheme

Place	Luminaire Unique ID	Quantity	Description of control type and operation technique
Reception/Entrance	PAL999	ww	DALI Dimmable, Daylight and Occupancy linked
Reception/Entrance	PAL999E	xx	DALI Dimmable, Daylight and Occupancy linked, Emergency lighting facility
Corridor/Ground floor	QAL888	yy	DALI, Occupancy linked
Corridor/Ground floor	QAL888E	zz	DALI, Occupancy linked, Emergency lighting facility

6.4.3 Existing building lighting system data

This method is applied to existing buildings that already have installed lighting systems. In this method a lighting audit has to be carried out in the building to establish the type and numbers of luminaires installed and the power rating of each luminaire type. The procedure for making the lighting audit is described in Annex D and the schedule of luminaires may be presented as shown in Table 4.

The information and data obtained will form the input to the energy estimation process. Once the installed lighting load is established the calculation procedure of the lighting energy requirement described in method 1 can be followed. The output of the method will be as described in 5.1 of the standard. This method may also be used for buildings that already have lighting controls or where it is considered or planned to add such controls.

6.4.4 Lighting system product data

For each place and for each luminaire type specified in the lighting scheme the electrical data as shown in Table 5 needs to be obtained from the manufacturer's product information sheet or from the lighting audit. The luminaire circuit power is the total power supplied to the luminaire with the lamps and the controls operating and charge power supplied to the emergency batteries. The Luminaire controls standby power and the emergency battery charge power are measured with the lamps in the luminaire switched off.

Table 5 — An example presentation of the required power data for luminaires in a place

Luminaire Unique ID	Luminaire circuit power (P_i) [W]	Luminaire controls standby power (P_{ci}) [W]	Luminaire standby emergency battery charge power (P_{ei}) [W]
PAL999	57,2	1,2	0,0
PAL999E	58,0	1,2	0,8
QAL888	27,2	1,2	0,0
QAL888E	28,2	1,2	1,0

For existing buildings during the lighting audit the data gathered can be organized into a similar table as indicated in Table 5. However, if the luminaire circuit power is not known then the rated power of the lamp may be used but if the lamp uses ballast or driver the luminaire power should be corrected as described in Annex D.

6.4.5 Lighting system dependency factors data

In this method the required system design data for each zone, room or building will consist of the details, dimensions and function of the building or place and the functional characteristics of the controls and the power ratings of the elements in the electric lighting system. The data will permit the calculation of the values of the various dependency factors F_0 , F_D and F_C for the place. The information required and the calculation process involved is given in more details in Annexes E, F and G respectively. The results of the calculations will show the amount of energy saving that can be made by the use of lighting controls. The details of some typical lighting controls are given Annex K.

NOTE For the occupancy dependency factor F_0 if a specific application space is not shown within the relevant part of the table and equivalent space from a different application space may be used. For example when determining F_A for an entrance hall in a manufacturing building using Table E.2 of EN 15193-1:2017 the information is given within the office application section of the data.

6.5 Operating conditions

The operating conditions are largely determined by the activity in the place, flexibility of the lighting system and the appropriateness of the lighting controls. To minimize the amount of energy used for lighting the electric lights should only be operated when there are occupants in the area and when there is insufficient daylight available to fulfil the required lighting criteria. It is accepted that the electric lighting system has been designed to provide the full lighting requirements for the area at any time when daylight is not available. However the electric lights should only be used to top up the available daylight to the design conditions and only when the area is occupied. For this process to function correctly a well-designed lighting control system should form an essential part of the lighting solution.

6.6 Calculation information

The calculation of the energy required for lighting involves three basic steps; the estimation of the installed power for lighting, the estimation of the operating times and the estimation of the energy saving impact of the lighting controls reacting to occupancy, daylight availability and lighting system maintenance.

The required steps in the lighting energy calculation method are shown in Figure 3. This shows that the first step is to establish the building type New or Existing and the second is to assess the lighting solution. From these data the installed power for lighting and the value of the dependency factors, the energy for illumination, for standby, the total energy and LENI are calculated.

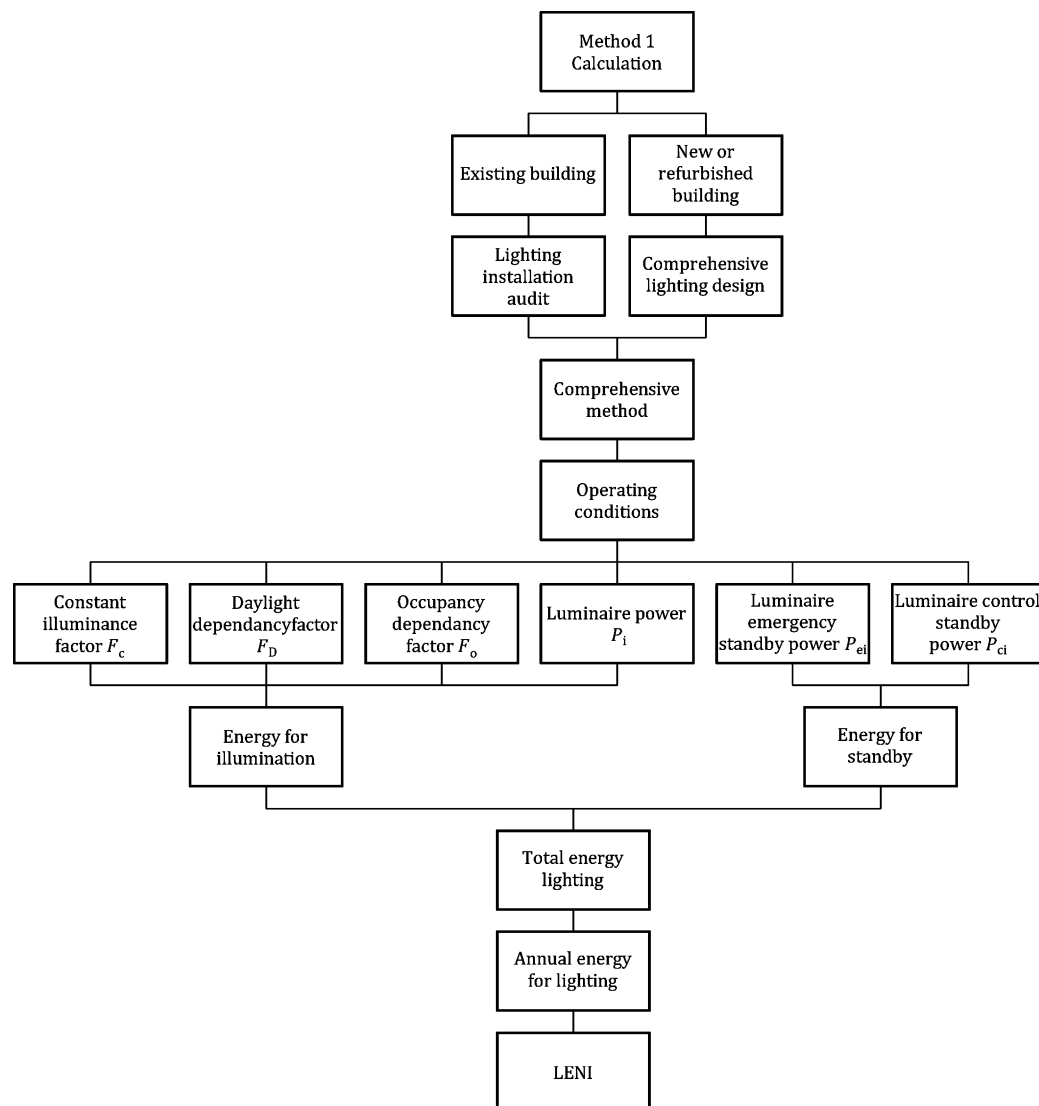
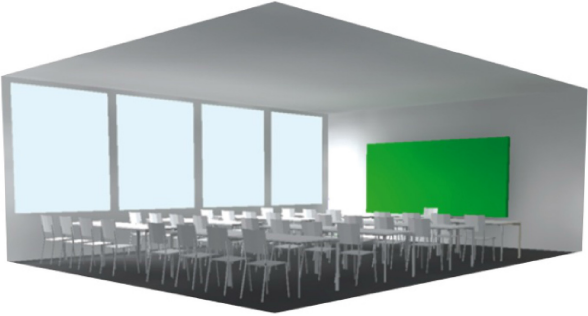


Figure 3 — Flow diagram for lighting energy calculations

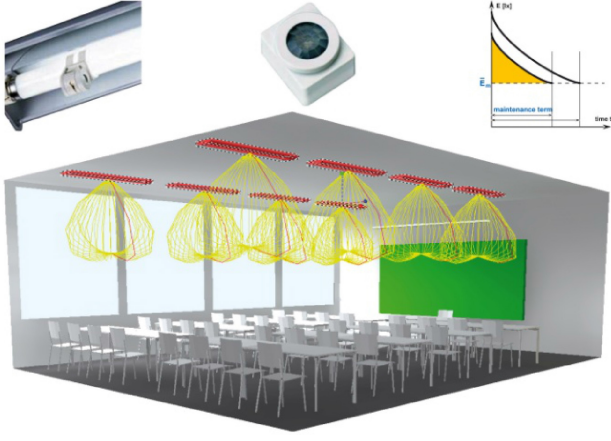
6.7 Expenditure factors for lighting systems

As LENI (Lighting Energy Numeric Indicator), represents the absolute amount of energy required for a lighting scheme it does not directly provide indications on the efficiency of the lighting technology employed. The concept of expenditure factors is therefore introduced to complement LENI, intending to render energy flows in lighting systems more transparent. As the same concept - or with efficiency factors as ratio of energy need to energy used being the inverted of the expenditure factors - are already well known for other building services systems like heating and cooling, the concept allows for a uniform and homogeneous rating over all building services systems by differentiating energy need and energy use. The expenditure factor for lighting systems is composed of partial expenditure factors for the respective technical installations. This includes the lighting control systems depending on presence of users and daylight conditions and the electric lighting system. Again, the latter can be broken down into the partial expenditure factors for light generation, distribution, and delivery. The concept of expenditure factors does not represent a new or alternative calculation method. Instead it only relates technical performance parameters of a lighting design to reference values. As it is not possible to assess the energy demand for lighting in general, it was necessary to define a reference lighting system with respective reference values.

Figure 4 gives a depiction of the influences (a) on the energy need for lighting W_{nd} and (b) of the determination of the expenditure factor for lighting systems by the partial expenditure factors.

	Space geometry $W_{nd}=f(\dots, \text{room index}, \dots)$
	Reflection $W_{nd}=f(\dots, \text{reflection coefficient}, \dots)$
	Façade $W_{nd}=f(\dots, \text{daylight availability}, \dots)$
	Usage: $W_{nd}=f(\dots, E_{task}, \text{usage time}, \text{absence}, \dots)$

a) Depiction of the influences on the energy need for lighting W_{nd}

	Electric lighting	$e_{L,ES}$
	Occupancy dependent control	$e_{L,O}$
	Daylight dependent control	$e_{L,D}$
	Constant illuminance control	$e_{L,C}$
	Expenditure factor for lighting	e_L

b) Depiction of the expenditure factor for lighting system e_l and of the partial expenditure factors

Figure 4 — Influences on the energy need for lighting and determination of the expenditure factor for lighting systems

6.7.1 Energy need and energy use for lighting

In general, the notion of energy need describes the energy a consumer receives from an appliance in the requested form (heat, light, drives, etc.). For lighting it can be described as follows: The energy need for lighting W_{nd} is the energy equivalent of the luminous flux that is required for electric space lighting (on the basis of defined lighting requirements), having been weighted with the effective operating time and assuming ideal lighting control (ideal use of appropriate potentials like absence, daylight and compensation for over-dimensioning due to maintenance of the electric lighting system). Whereas the energy use generally describes the amount of energy to be supplied to the corresponding subsystem. For lighting it reflects the electrical energy input to a lighting system.

The energy need for lighting W_{nd} includes all influences, which are not to be attributed to the efficiency of the lighting technology, such as:

— Usage

- Requirements pertaining to the visual task: Generally, spaces that have to meet high requirements with regard to the visual task are characterized by higher values of maintained illuminance and by higher requirements to the luminance distribution within the space - these spaces are hence distinguished by higher values of W_{nd} compared to spaces complying with less strict requirements. As a consequence, W_{nd} depends on the requirements for the visual tasks.
- Usage times: Generally, frequently occupied spaces with long usage times are characterized by higher values of W_{nd} (due to the longer effective operating time of the lighting system) compared to spaces with shorter usage times. Spaces that are occupied primarily at night (prevailing night-time usage) will be characterized by higher values of W_{nd} than comparable spaces with prevailing day-time usage.
- Relative absence: any long relative absence (i.e. a non-occupied space) will reduce W_{nd} .
- Maintenance of lighting installations: spaces distinguished by high maintenance factors (e.g. due to minor, use-related pollution of luminaires and spaces) require less over-dimensioned new lighting installations; from this, a smaller amount of energy need W_{nd} will result.
- Space geometry

Due to a relatively higher light absorption of the enclosing surfaces, small compact spaces will need higher luminous fluxes to fulfil the requirements on indoor space illuminances and luminances, which is why they have higher values of W_{nd} than large, wide rooms.

- Reflection coefficients of space enclosing surfaces

Dark spaces require higher luminous fluxes to meet the requirements on indoor space illuminances and luminances, therefore they are characterized by higher values of W_{nd} than spaces enclosed by bright-coloured surfaces.

- Façade geometry and photometry, location, climate

Spaces that are poorly supplied with daylight cause higher effective operating times (hence, higher values of W_{nd}) than spaces benefitting from good daylight supply. The energy use for lighting W_{us} corresponds to the calculated amount of an energy carrier (usually electricity) that is needed to cover the energy need for lighting.

6.7.2 Expenditure factor for lighting

6.7.2.1 General

In general, an expenditure factor describes the ratio between cost (expenditure) and benefit, thus forming the reciprocal value of a utilization factor. According to the above given definitions, it can be written:

$$W_{nd} = p_{Ref} \cdot [A_D (t_{Day} \cdot F_{D,Ref} \cdot F_{O,Ref} \cdot F_{C,Ref} + t_{Night} \cdot F_{O,Ref} \cdot F_{C,Ref}) + A_{ND} (t_{Day} \cdot F_{O,Ref} \cdot F_{C,Ref} + t_{Night} \cdot F_{O,Ref} \cdot F_{C,Ref})] \quad [\text{kWh}] \quad (1)$$

This amount of energy need will be supplied by the actually installed lighting system, requiring the following energy input or expenditure, termed energy use W_{us} :

$$W_{us} = p \cdot [A_D (t_{Day} \cdot F_D \cdot F_O \cdot F_C + t_{Night} \cdot F_O \cdot F_C) + A_{ND} (t_{Day} \cdot F_O \cdot F_C + t_{Night} \cdot F_O \cdot F_C)] \quad [\text{kWh}] \quad (2)$$

The expenditure factor for lighting systems is obtained as ratio of the two above given energy demands:

$$e_L = \frac{\text{energy use}}{\text{energy need}} = \frac{W_{us}}{W_{nd}} \quad (\text{standard Formula 16})$$

As said before, it can be derived by formal separation of the individual influences for constant illuminance control, for occupancy dependent and daylight dependent lighting control as well as for the electric lighting system. Each of these influences is described by a partial expenditure factor, whose multiplication result in the expenditure factor for lighting systems (see standard Formula 17). These partial factors and their derivation will be described in the following paragraphs. In general, they all account for the efficiency of the respective component, compared to an ideal system, which is expressed by a ratio, with the ideal system covered in the denominator.

$$e_L = e_{L,C} \cdot e_{L,O} \cdot e_{L,D} \cdot e_{L,ES} \quad (\text{standard Formula 17})$$

6.7.2.2 Partial expenditure factor for constant illuminance control $e_{L,C}$

The partial expenditure factor for constant illuminance control accounts for the efficiency of the constant illuminance control and depends on the maintenance factor. It is calculated by the following formula:

$$e_{L,C} = \frac{1 - \frac{1}{2} F_{CC} (1 - MF)}{1 - \frac{1}{2} (1 - MF)} \quad (\text{standard Formula 18})$$

where

F_{CC} is the factor for the efficiency of the constant illuminance control.

NOTE The impact of the over-design of schemes (for example modular spacing) is under consideration.

An ideal constant illuminance control with $F_{CC} = 1$ will dim the light exactly at the maintained illuminance, thus resulting in a partial expenditure factor of $e_{L,C} = 1$. The absence of constant illuminance control, i.e. $F_{CC} = 0$ will result in the undimmed operation of the system, thus requiring higher energy inputs. Assuming a maintenance factor (MF) of 0,6 and $F_{CC} = 0$, a partial expenditure factor $e_{L,C} = 1,25$ will result; assuming MF = 0,9, the partial expenditure factor will be $e_{L,C} = 1,05$, and for the reference-MF of 0,8 it will be $e_{L,C} = 1,11$.

The dependency of the partial expenditure factor for constant illuminance control is illustrated in Figure 5. The reference MF given in Annex C of the standard is marked.

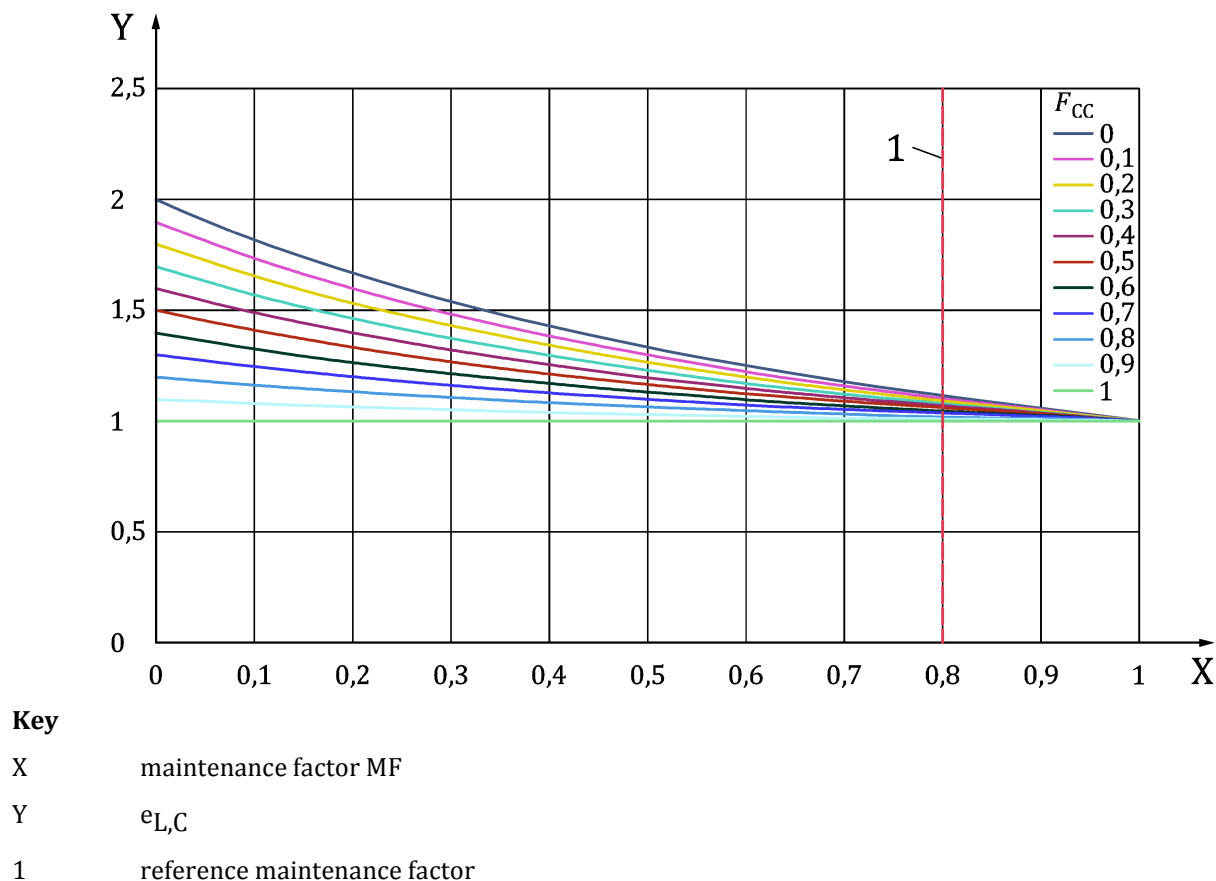


Figure 5 — Illustration of the partial expenditure factor for constant illuminance control $e_{L,C}$ as a function of the efficiency factor for constant illuminance control F_{CC} and the maintenance factor MF

6.7.2.3 Partial expenditure factor for occupancy dependent lighting control $e_{L,O}$

The partial expenditure factor for occupancy dependent lighting control takes the energy saving potential of occupancy dependent lighting control into account. It is calculated by dividing the occupancy dependency factor F_O , accounting for the type of system and its effect depending on the type of usage, by the relative presence in the area under consideration (derived by $1 - F_A$)

$$e_{L,O} = \frac{F_O}{(1 - F_A)} \quad (\text{standard Formula 19})$$

An ideal occupancy detection system will fully recognize the absence of persons and switch off the lights, which will produce a partial expenditure factor equal to 1. Manual switching in response to room occupancy, for instance in a cellular 1 person office ($F_A = 0,4$ according to Annex E) with manual switch ($F_O = 0,8$) will result in an expenditure factor of $e_{L,C} = 1,33$. If an automatic presence detection system with $F_{OC} = 0,9$ ($F_O = 0,7$) was installed in the same type of space this would result in a partial expenditure factor of $e_{L,C} = 1,17$

Figure 6 illustrates the dependency of the partial expenditure factor for occupation control. The normative values for F_{OC} as specified in Annex E have been marked.

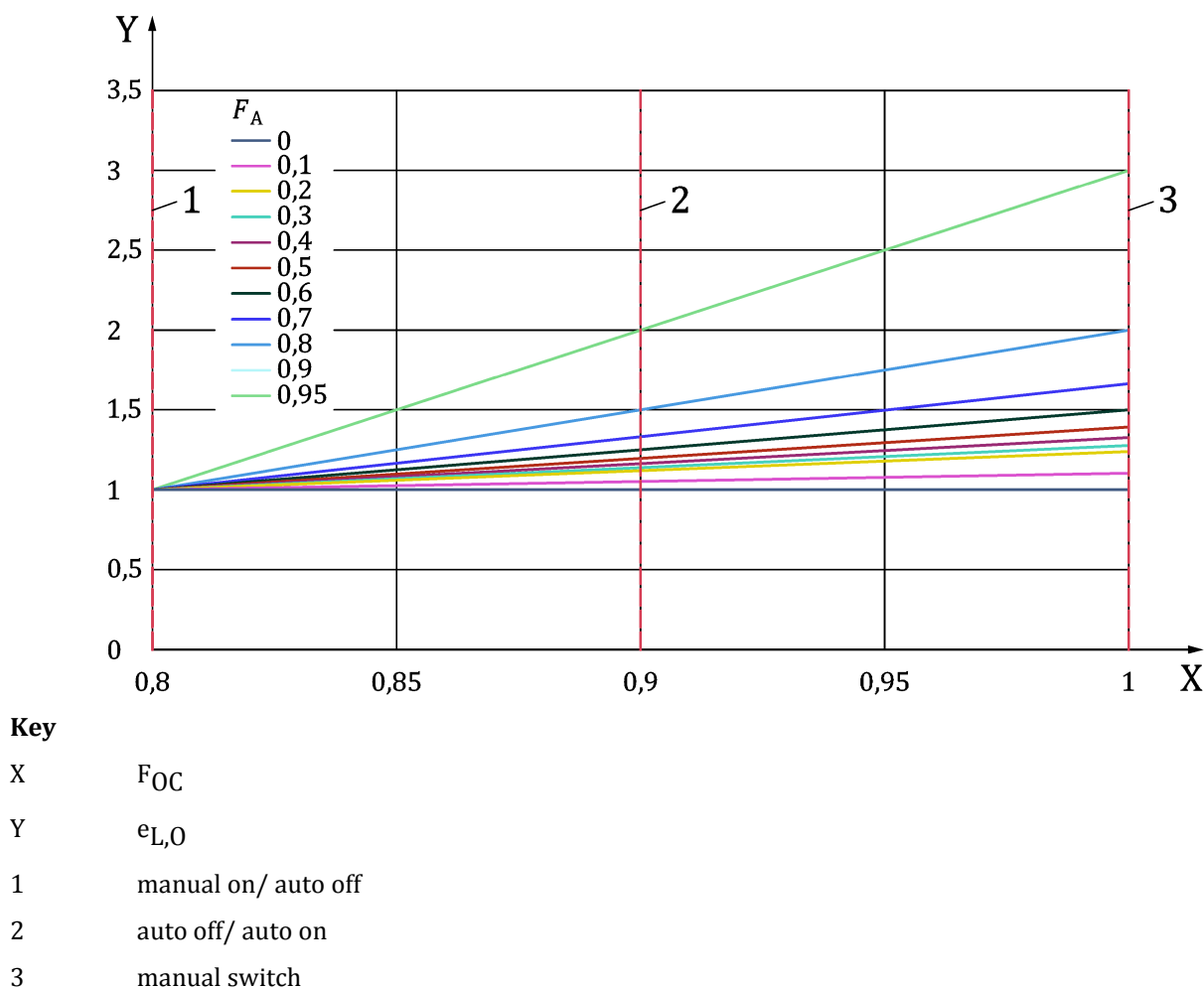


Figure 6 — Illustration of the partial expenditure factor for occupancy dependent lighting control $e_{L,O}$ as a function of the controls function factor F_{OC} and the absence factor F_A

6.7.2.4 Partial expenditure factor for daylight dependent lighting control $e_{L,D}$

The partial expenditure factor for daylight dependent lighting control correlates the effect of the actual control system to the ideal case. The formula (standard Formula 20) also accounts for the fact that this control system does neither affect the lighting energy demand in areas not benefitting from daylight nor the one during night time hours.

$$e_{L,D} = \frac{A_D \left[t_{\text{Day}} \cdot (1 - F_{D,S} \cdot F_{D,C}) + t_{\text{Night}} \right] + A_{ND} (t_{\text{Day}} + t_{\text{Night}})}{A_D \left[t_{\text{Day}} \cdot (1 - F_{D,S}) + t_{\text{Night}} \right] + A_{ND} (t_{\text{Day}} + t_{\text{Night}})} \quad (\text{standard Formula 20})$$

When applying the standard's quick method 2, $F_{D,C} = 0,52$, as manual daylight-responsive control is assumed (see 7.4.3.5 of the standard, Formula 30).

An ideal daylight control system will use electric lighting to supplement the available amount of daylight precisely up to the point where the required illuminance is achieved, thus resulting in a partial expenditure factor of 1. For instance, manual daylight-dependent lighting control in a personal office with "strong daylight availability" ($t_D = 2\,250$ h; $t_N = 250$ h, see Annex B of the standard, Table B.2) and $E_m = 500$ lx with $F_{D,C} = 0,57$ (see Annex F of the standard, Table F.16) in a fully daylight-supplied single-occupant office (i.e. $A_D = A$ or $A_{D,\text{normalized}} = 1$) with $F_{D,S} = 0,7$ will result in an expenditure factor of

$e_{L,D} = 1,73$. For automated daylight control (dimmed, stand by losses, no switch-on) with $F_{D,C} = 0,8$, a value of $e_{L,D} = 1,34$ will result under the same boundary conditions. If only half of the room is receiving daylight (i.e. $A_D = A_{ND} = A/2$ or $A_{D,normalized} = 0,5$), the value for the automated system will be $e_{L,D} = 1,09$.

The partial expenditure factor for the daylight-dependent control of electric lighting $e_{L,D}$ is illustrated in Figure 7 for several typical parameter settings.

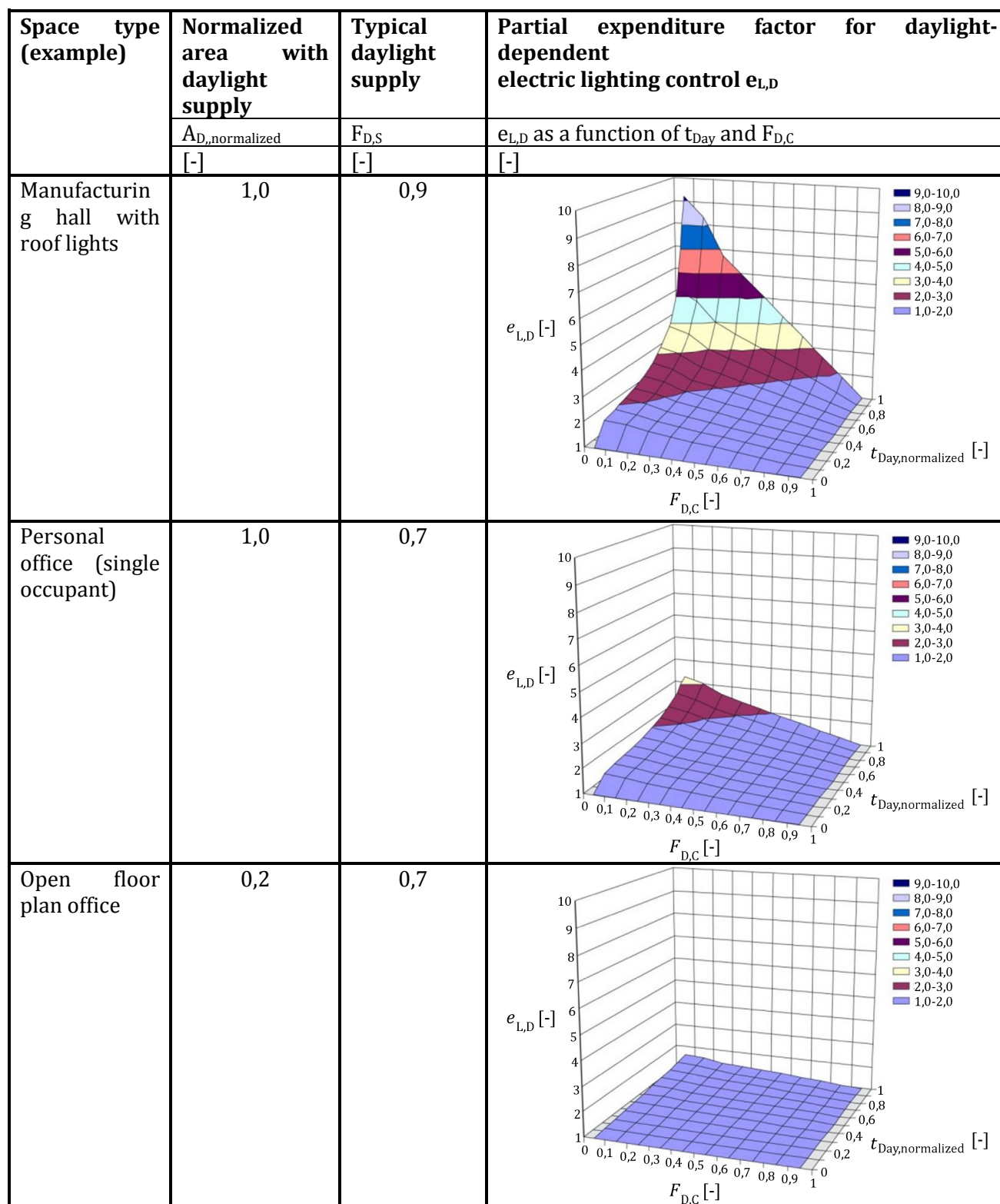


Figure 7 — Illustration of the partial expenditure factor for daylight dependent electric lighting control $e_{L,D}$ as a function of the normalized daytime $t_{Day,normalized}$ ($t_{Day,normalized} + t_{Night,normalized} = 1$), the efficiency factor for constant illuminance control $F_{D,C}$ for different values of the normalized area with daylight supply $A_{D,normalized}$ ($t_{D,normalized} + A_{ND,normalized} = 1$), and varying daylight supply factors $F_{D,S}$

6.7.2.5 Partial expenditure factor for the electric lighting system $e_{L,ES}$

Corresponding to the other partial expenditure factors, $e_{L,ES}$ is an object-related parameter. On the one hand, a luminaire will thus imply two different expenditure factors in two different room situations. On the other hand, this circumstance will also allow to directly compare the energy performance of two different luminaires in one room situation. This approach is similar to the principle of balance calculations used in other evaluation areas (heating, cooling, ventilation).

The partial expenditure factor for the electric lighting system correlates the installed electric power density P with the electrical evaluation power for supplying the luminous flux that is needed to fulfil the use-related requirements, when applying a reference system defined for this purpose. How to determine these power densities and the resulting factor, respectively, depends on the calculation method applied. The determination according to the following three different approaches will be introduced in the following:

- a) Comprehensive calculation method 1 of the standard
- b) Simplified utilization factor method (introduced in this Technical Report)
- c) Quick calculation method 2 of the standard (derived from the simplified utilization factor method)

As all approaches rely on the definition of a reference light source, this will be introduced next.

Reference light source: luminous efficacy and luminous intensity distribution

For the determination of expenditure factors, it is necessary to define a reference light source. Analysing the composition of a light source's optical radiation spectrum, the luminous efficacy η_L , the (most similar/close) colour temperature T and the general colour rendering index R_a can be clearly determined. Theoretically, the target function of an ideal light source should ensure the highest possible luminous efficacy ($\eta_L = 683 \text{ lm/W}$), the highest possible colour rendering index ($R_a = 100$) and the independence of the light colour. Physically, such a light source cannot be realized.

Based on the assumptions that fluorescent lamps and discharge lamps can be considered to be fully developed and technically mature and LEDs are expected to become an important light source in future and to be further developed, a reference luminous efficacy of 140 lm/W was chosen. This is estimated to be a realistic, feasible value for LEDs. Further, there is also a relation to natural lighting using daylight. For clear skies, the luminous efficacy of radiation can be found to take on values in this range. The value of 140 lm/W was determined being well aware of the fact that by this convention expenditure factors < 1 might occur in selected illumination solutions using specialized lamps (like sodium-vapour lamps).

A reference luminous intensity distribution should meet the lighting requirements in accordance with standard EN 12464-1 or EN 12193 in an ideal way with regard to energy performance. As such a luminous intensity distribution curve (I-table) cannot be specified independent of a certain object, it is only possible to make an agreement concerning a real I-table that meets the requirements in good approximation and which should be used as a reference.

In general, the requirements concerning the use of energy can be fulfilled most efficiently by using direct lighting systems. For horizontal work planes as well as regarding further requirements, e.g. concerning the cylindrical illuminance inside the space, the highest room utilization factors will result for light distribution A50. This type is thus applied as reference luminous intensity distribution. Since luminous intensity distributions (I-table) also vary within one class, exactly one distribution of the type will be selected to satisfy the required uniqueness.

a) Determination of $e_{L,ES}$ when applying the standard's method 1 (comprehensive calculation)

Within method 1, the installed power and resulting therefrom the installed power density is derived by simulation of the lighting situation, during the comprehensive lighting system design. In consequence, the power density of the reference lighting system needs to be calculated accordingly. This means, a respective lighting situation with the reference light source as defined above in the area under consideration needs to be computed.

b) Determination of $e_{L,ES}$ when applying the simplified utilization factor method

The power densities and thus the partial expenditure factor for the electric lighting system can be determined from the luminous efficacy, the energy expenditure factor of the lamp operating device and the light output ratio (luminaire efficiency) as well as the room utilization factor, as demonstrated in the following Formula 21 of the standard. These parameters are generally available. The formula can be further rearranged corresponding to the influences of delivery, distribution and generation of electric light. Consequently also the partial expenditure factor can be derived by formal separation of these different effects, for which partial expenditure factors ($e_{L,ES,del}$, $e_{L,ES,dis}$, $e_{L,ES,gen}$) were introduced

$$e_{L,ES} = \frac{P}{P_{Ref}} = \frac{\frac{\Phi}{F_{U,e} \cdot \eta_{LB,Ref} \cdot \eta_{L,Ref} \cdot \frac{1}{f_{B,ref}}}}{\frac{\Phi}{F_U \cdot \eta_{LB} \cdot \eta_L \cdot \frac{1}{f_B}}} \quad \text{(standard Formula 21)}$$

$$= \frac{F_{U,e}}{F_U} \cdot \frac{\eta_{LB,Ref}}{\eta_{LB}} \cdot \frac{\eta_{L,Ref} \cdot f_B}{\eta_L \cdot f_{B,ref}} = e_{L,ES,del} \cdot e_{L,ES,dis} \cdot e_{L,ES,gen}$$

Partial expenditure factor for delivery of electric light

The partial expenditure factor for delivery of electric light describes the emission of the luminous flux emitted from luminaires to the inside of the space (work plane). It establishes an object-specific relation (i.e. taking into account the space geometry and the respective space reflection coefficients) between the actual room utilization factor for the luminous intensity distribution of the selected luminaire and for a reference luminous intensity distribution. It is calculated using Formula (23) of the standard:

$$e_{L,ES,del} = \frac{F_{U,e}}{F_U} \quad \text{(standard Formula 23)}$$

For rectangular rooms, the utilization factor F_U can simplified be determined as a function of the room index and upward flux fraction (UFF) using Table 6. This table also includes the reference utilization factor, which represents the values of a direct A50-system with UFF=0 %.

Table 6— Utilization factors (actual and reference) as a function of the room index k and the upward flux fraction

Upward flux fraction (UFF)	Room index k									
	0,6	0,8	1	1,25	1,5	2	2,5	3	4	5
10 % (direct)	0,45	0,52	0,56	0,62	0,64	0,69	0,72	0,76	0,79	0,79
30 % (dir./ind.)	0,39	0,44	0,48	0,51	0,54	0,57	0,60	0,62	0,64	0,67
70 % (ind./dir.)	0,26	0,31	0,36	0,41	0,45	0,51	0,56	0,57	0,64	0,67
90 % (indirect)	0,19	0,24	0,28	0,33	0,36	0,43	0,48	0,52	0,57	0,62
Reference case (UFF=0 %) $F_{U,e}$	0,50	0,61	0,69	0,78	0,84	0,90	0,95	0,99	1,03	1,05
NOTE Intermediate values of the room index can be interpolated.										

For the determination of the values given in the table the following typical reflection coefficients were applied: ceiling: 70 %, walls: 50 %, floor: 20 %.

Partial expenditure factor for distribution of electric light

The partial expenditure factor for distribution of electric light relates the actual luminaire efficiency to the ideal luminaire efficiency ($\eta_{LB,Ref} = \eta_{LB,ideal} = 1$). It thus describes the luminaires' light distribution efficiency, i.e. the distribution efficiency of the light emitted from the lamps through the luminaires. In consequence, this factor is equivalent to the reciprocal of the luminaire light output ratio η_{LB} .

Partial expenditure factor for generation of electric light

The partial expenditure factor for generation of electric light relates the actual luminous efficacy and the efficiency of the light source's operating device to a reference luminous efficacy and an ideal operation of the light sources ($f_{B,Ref} = f_{B,ideal} = 1$). Information on the reference light source are given below.

c) Determination of $e_{L,ES}$ when applying the standard's method 2 (quick calculation)

Like the calculation procedure of method 2 is derived from the simplified utilization factor method, this also applies for the determination of the partial expenditure factor for the electric lighting system. Applying the formulation of the installed power, according to the simplified method from Annex C, the standard Formula (23) can be rearranged and simplified as shown below, when the design influences of the maintained illuminance, the maintenance factor and the surrounding area are regarded to be equal in both cases (reference and actual situation). In addition, the ratio of the power density values can be replaced by the above given quotient of the utilization factors, which depends on the room index.

$$\begin{aligned}
 e_{L,ES} &= \frac{P}{P_{Ref}} = \frac{P_{j \cdot lx} \cdot E_{task} \cdot F_{MF} \cdot F_{CA} \cdot F_L}{P_{j \cdot lx,Ref} \cdot E_{task} \cdot F_{MF} \cdot F_{CA} \cdot F_{L,Ref}} = \frac{P_{j \cdot lx} \cdot F_L}{P_{j \cdot lx,Ref} \cdot F_{L,Ref}} = \\
 &= 2,33 \frac{P_{j \cdot lx}}{P_{j \cdot lx,Ref}} \cdot F_L = 2,33 \frac{F_{U,e}}{F_U} \cdot F_L
 \end{aligned} \quad (3)$$

With

$$F_{L,Ref} = \frac{60lm/W}{140lm/W} = \frac{3}{7} = \frac{1}{2,33}$$

6.7.3 Application of expenditure factors

6.7.3.1 General

Besides rating the efficiency of the lighting situation, the application of expenditure factors allow an easy and at the same time very meaningful comparison of old and new systems. In offices, for instance, the expenditure factors for common electric lighting systems vary between values close to 2 for efficient (newly installed) lighting systems and frequently > 6 for old installations. If new systems are provided with appropriate light management systems, overall expenditure factors between 2 and 3 will result, while manually operated lighting systems will produce factors close to 7. For existing systems, which are rarely equipped with light management components, even expenditure factors >10 may result. Figure 8 presents an example of the energy flow density defined on the basis of expenditure factors for a personal office lit by an existing system. In Figure 9 an old and a new system are compared.

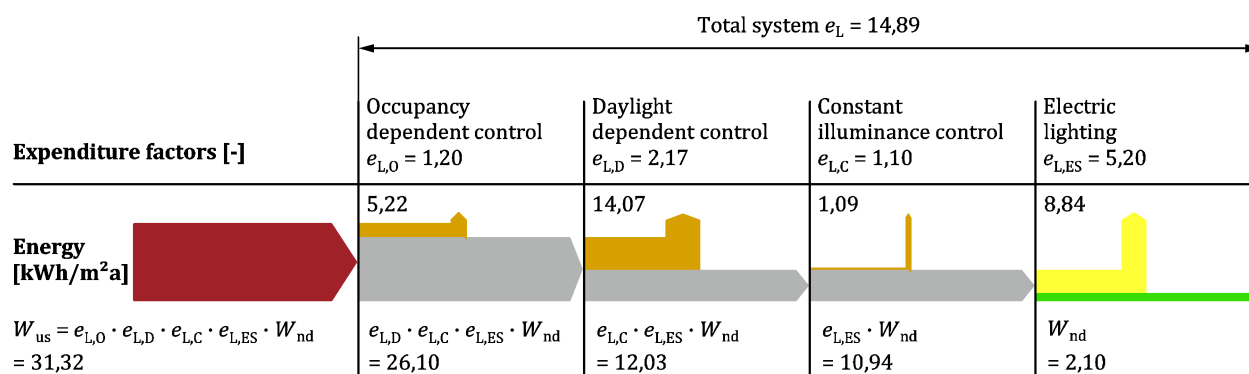


Figure 8 — Example of the energy flows in a single-occupant office with an existing lighting system

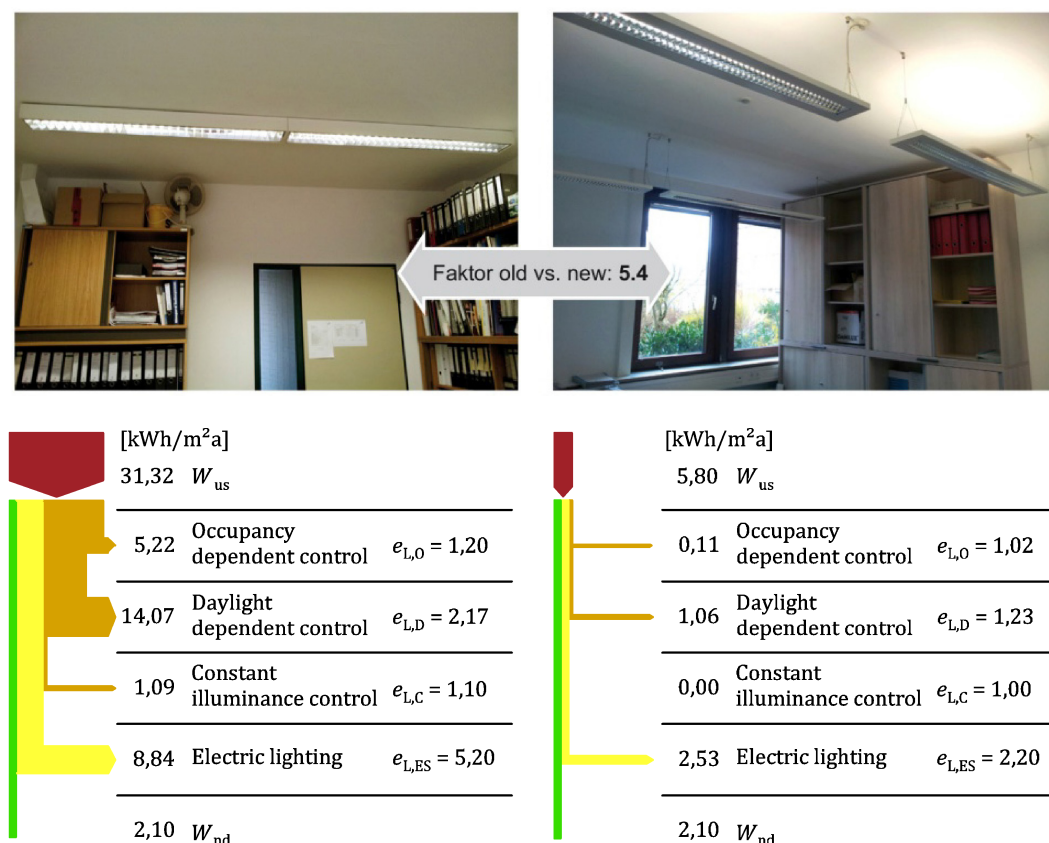


Figure 9 — Comparable example of the energy flows in a single-occupant office with a new and an old system

6.7.3.2 Example calculation of expenditure factors for lighting systems

In the following, example calculations for several cases are presented. In a first step, seven different space types will be defined and parameterized. Then, the partial expenditure factors for the electric lighting system will be determined for various system configurations used in practice. As considered most illustrating, this will be done according to the determination of $e_{L,ES}$ following method b, applying the simplified utilization factor method. Lastly, the associated energy need, the expenditure factor, and the energy use for lighting will be determined and discussed for the typical variations of the space types, the electric lighting systems, and the lighting control solutions.

6.7.3.3 Space types under consideration

The seven typical space geometries under consideration are presented in Figure 10. The parameter settings of the respective spaces are given in Table 7.

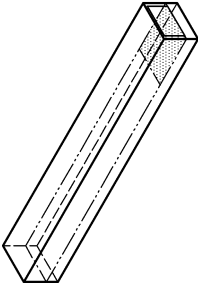
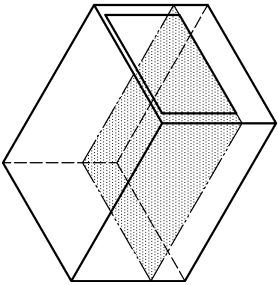
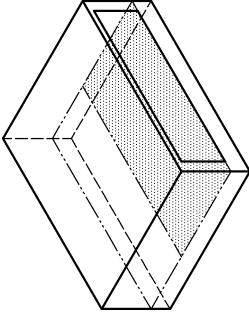
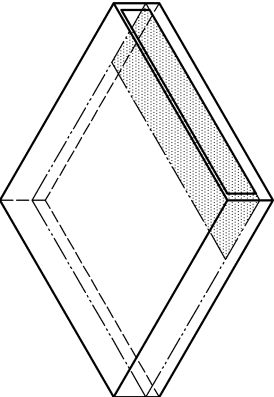
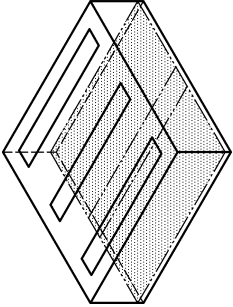
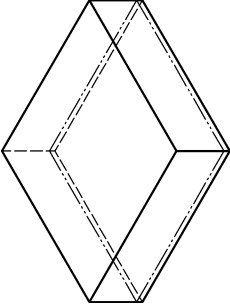
		
a) Circulation area	b) Personal office (single occupant)	c) Conference room
		
d) Open floor office/ e) Kitchen in non-residential buildings	f) Manufacturing hall with roof lights	g) Manufacturing hall without roof lights
NOTE The areas benefitting from daylight are shown in dark grey.		

Figure 10 — Typical spaces under consideration

Table 7 — Parameter setting of the seven considered space types

N o .	Space type	Dimensions a × b × h [m] × [m] × [m]	Floor space [m ²]	Room index k _a for illumination type		Area of floor space illuminated by daylight A _p [m ²]	Daylight supply factor in daylight area F _{D,S} [%]	Day-time usage hours per annum t _{Day} [h]	Night-time usage hours per annum t _{Night} [h]	Relative. absence F _A [-]	Maintained illuminance E _m [lx]	Maintenance factor MF [-]
				dir	dir/ind ^b							
1	Circulation area	1,8 × 24,8 × 2,8	44,6	0,6	0,80	12,2	72,8	2250	250	0,8	100	0,8
2	Personal office (single occupant)	3,6 × 4,5 × 2,8	16,2	1,0	1,30	16,2	75,8	2250	250	0,4	500	0,8
3	Conference room	9 × 7,2 × 2,8	64,8	2,0	2,67	39,9	76,3	2250	250	0,5	500	0,8
4	Open floor office	16 × 16 × 2,8	256	4,0	5,30	76,0	76,7	2250	250	0	500	0,8
5	Kitchen in non-residential buildings	16 × 16 × 2,8	256	4,0	5,30	76,0	76,7	1250	1250	0	500	0,8
6	Manufacturing hall with roof lights	32 × 32 × 8,8	1024	2,0	-	1024	94	2500	1500	0	500	0,7
7	Manufacturing hall without roof lights	32 × 32 × 8,8	1024	2,0	-	0	0	2500	1500	0	500	0,7
The assumed reflection coefficients (ρ) are floor = 20 %; wall = 50 %; ceiling = 70 %.												
a	Assumed height of task area: 0,8 m											
b	Height of luminaire plane: 2,5 m											

6.7.3.4 Partial expenditure factors for the electric lighting system

Example partial expenditure factors for different configurations of electric lighting systems will be given in Table 8, matching the spaces considered in Figure 10 and Table 7. Table 9 specifies the associated values of installed power P_{ref} and P . For a lighting system featuring an ideal (by definition) energy performance with a reference luminous efficacy $\eta_{\text{L,ref}} = 140 \text{ lm/W}$, lossless ballast $f_{\text{B}} = 1$ and a lossless light distribution through the luminaire of $\eta_{\text{LB,ref}} = 1$, a partial expenditure factor of $e_{\text{L,ES}} = 1,0$ will result. For commonly used electric lighting systems, example values are ranging between 2,2 and 3,3. The example value given for the floor area is 4,3, which is due to the lower luminous efficacy of compact fluorescent lamps compared to that of customary tubular lamps generally used in offices. By replacing sodium vapour lamps ($\eta_{\text{L}} = 180 \text{ lm/W}$) in industrial areas (which have only minor or zero requirements regarding the general colour rendering index), an expenditure factor of $e_{\text{I,K}} = 1,4$ will be determined. Halls equipped with metal-halide vapour lamps have typical partial expenditure factors of $e_{\text{I,K}} = 2,6$. Regarding existing office lighting systems, an old system with T12-lamps, CB, luminaires with inefficient reflectors and an assumed value of $\eta_{\text{LB}} = 0,5$ will have partial expenditure factors of $e_{\text{I,K}} = 6,5$. With this, the existing system exceeds by factor 2,5 the value of an energy-efficient new installation for the same type of usage. When comparing an existing halogen-lamp system for manufacturing hall and corridor lighting (space type: floor area) with a common-type new installation, the difference in energy efficiency will be approximately equal to factor 4.

Table 8 — Examples of expenditure factors for the electric lighting system

Illumination solution		Lamp	Ballast	Luminaire		Partial expenditure factors			
		η_L	f_B	Light Output Ratio $\eta_{L,B}$	Upward Flux Fraction (UFF)	$e_{L,ES,del}$	$e_{L,ES,dis}$	$e_{L,ES,gen}$	$e_{L,ES}$
Ideal energy system		[lm/W]	[-]	[-]	[-]	[-]	[-]	[-]	[-]
Circulation area	Standard, direct	140	1,0	1,00	0 % (A50)	1,0	1,0	1,0	1,0
	Existing, direct	50 (CFL)	1,1 (EB)	0,80	10 %	1,11	1,25	3,08	4,27
Personal office	Efficient, direct	15 (halogen)	1,1 (transformer)	0,70	10 %	1,11	1,43	10,27	16,28
	Efficient, dir / ind	100 (T5)	1,1 (EB)	0,85	10 %	1,24	1,18	1,54	2,25
	Standard, direct	100 (T5)	1,1 (EB)	0,90	30 %	1,54	1,11	1,54	2,64
	Standard, dir / ind	90 (T5)	1,1 (EB)	0,70	10 %	1,24	1,43	1,71	3,03
	Existing, direct	90 (T5)	1,1 (EB)	0,80	30 %	1,54	1,25	1,71	3,29
	Existing, direct/indirect	70 (T12)	1,3 (CB)	0,50	10 %	1,24	2,00	2,60	6,45
Conference room	Efficient, dir / ind	70 (T12)	1,3 (CB)	0,50	30 %	1,54	2,00	2,60	8,01
Open office	Efficient, dir / ind	100 (T5)	1,1 (EB)	0,90	30 %	1,60	1,11	1,54	2,74
	Existing, direct	100 (T5)	1,1 (EB)	0,90	30 %	1,58	1,11	1,54	2,70
Kitchen (non-residential building)	Efficient, direct	70 (T12)	1,3 (CB)	0,50	10 %	1,30	2,00	2,60	6,76
	Existing, direct	100 (T5)	1,1 (EB)	0,85	10 %	1,30	1,18	1,54	2,36
Manufacturing hall	Efficient, direct I	70 (T12)	1,3 (CB)	0,50	10 %	1,30	2,00	2,60	6,76
	Efficient, direct II	180 (SON)	1,1 (CB)	0,80	10 %	1,30	1,25	0,86	1,39
	Efficient, direct III	96 (HMI)	1,1 (CB)	0,80	10 %	1,30	1,25	1,60	2,61
	Existing, direct	100 (T5)	1,1 (EB)	0,85	10 %	1,30	1,25	1,54	2,50
		70 (T12)	1,3 (CB)	0,50	10 %	1,30	2,00	2,60	6,76

Table 9 — Examples of partial expenditure factors for the lighting system and installed power

Space type	Installed power for determining the energy need	Illumination solution	Partial expenditure factor	Installed power of the actually installed system
	P_{ref}		$e_{L,ES}$	P
	$[W/m^2]$		$[-]$	$[W/m^2]$
Circulation area	1,81	Standard, direct	4,27	7,74
		Existing, direct	16,28	29,47
Personal office	5,42	Efficient, direct	2,25	12,18
		Efficient, dir / ind	2,64	14,28
		Standard, direct	3,03	16,43
		Standard, dir / ind	3,29	17,85
		Existing, direct	6,45	34,95
		Existing, direct / indirect	8,01	43,40
Conference room	4,52	Efficient, dir / ind	2,74	12,37
Open floor office	3,97	Efficient, dir / ind	2,70	10,73
		Existing, direct	6,76	26,84
Kitchen (non-residential building)	4,90	Efficient, direct	2,36	11,54
		Existing, direct	6,76	33,12
Manufacturing hall	5,10	Efficient, direct I	1,39	7,09
		Efficient, direct II	2,61	13,29
		Efficient, direct III	2,50	12,76
		Existing, direct	6,76	34,48

6.7.3.5 Sample expenditure factors for lighting systems

Amongst others, Table 10 depicts the determined energy need values. They range between $W_{nd} = 0,6 \text{ kWh/m}^2\text{y}$ (floor area) and $W_{nd} = 16,6 \text{ kWh/m}^2\text{y}$ (industrial halls). The low amount of energy need determined for the floor area is basically due to the relatively low maintained illuminance of $E_m = 100 \text{ lx}$ and the high relative absence of $F_A = 0,8$. The high value obtained for the industrial hall without rooflights results from the relative maintained illuminance of $E_m = 500 \text{ lx}$ and the low relative absence of $F_A = 0$ in conjunction with a high number of annual usage hours. In both cases, daylight supply is not sufficient, as either not represented or the area which is illuminated by daylight is rather small in relation to the floor area of the respective space type. By contrast, the pronounced influence daylight supply has on the energy need becomes quite clear on comparing variation #6 (hall with roof lights) with an energy need value of $W_{nd} = 0,6 \text{ kWh/m}^2\text{y}$ and variation #7 (hall without roof lights) with $W_{nd} = 16,6 \text{ kWh/m}^2\text{y}$. The energy need values of the other space types given are to interpret accordingly.

Using efficient new installations with automatic illumination control systems expenditure factors of approximately 1,8 to 2,8 can be realized. For instance, if lighting control systems are not used in offices that are equipped with efficient luminaire technology, the expenditure factor will rise to values between 2,7 and 6,3, depending on the energy need of the space type. Example calculations for an existing personal office lighting system result in an expenditure factor of approximately 15, thus requiring an energy input that is about 6 times as much as that of an energy-efficient new lighting system. In the case of the described open-plan office, the difference between an efficient new lighting installation with direct/ indirect lighting and an old system with direct lighting is approximately 2,7.

The energy use W_{us} is then obtained by multiplying the energy need W_{nd} and the expenditure factor. The calculated example final energies range between 1,6 kWh/m²y (variation #1.a.I: floor area, standard – direct with automatic lighting control) and 59,8 kWh/m²y (variation #7.d.I: hall without roof lights, existing - direct with manual lighting control).

Table 10 — Energy needs, expenditure factors and energy uses for illumination for the spaces und lighting installations under consideration

No.			Space type	Energy need	Electric lighting system	Partial expenditure factor	Illumination control				Expenditure factor for lighting	Energy use	
							Partial expenditure factors						
				Type			e _{L,O}	e _{L,D}	e _{L,C}	E _L			
				Type			[-]	[-]	[-]				[kWh/m ² y]
1	a	I	Circulation area	0,6	Standard, direct	4,27	Automatic	1,50	1,04	1,00	6,67	4,31	
		Manual					2,00	1,11	1,11	10,54	6,81		
2	b	I		Existing, direct	16,28	Efficient, direct	2,25	Automatic	1,17	1,43	1,00	3,76	6,00
		Manual	1,33					2,07	1,11	6,87	10,97		
	c	I	Efficient, dir/ind	2,64	Automatic	1,17	1,43	1,00	4,41	7,04			
		Manual			1,33	2,07	1,11	8,06	12,86				
	d	I	Standard, direct	3,03	Manual	1,33	2,07	1,11	9,27	14,80			
		Manual			1,33	2,07	1,11	10,08	16,08				
3	e	I	Existing, direct	6,45	Manual	1,33	2,07	1,11	19,72	31,47			
		Manual			1,33	2,07	1,11	24,50	39,09				
4	f	I	Existing, direct/indirect	8,01	Automatic	1,20	1,15	1,00	3,78	9,91			
		Manual			1,40	1,37	1,11	5,83	15,30				
	a	I	Efficient, dir/ind	2,70	Automatic	1,00	1,05	1,00	2,84	19,43			
		Manual			1,00	1,13	1,11	3,39	23,23				
	b	I	Existing, direct	6,76	Manual	1,00	1,13	1,11	8,49	58,08			
		Manual			1,00	1,13	1,11	8,49	58,08				

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No.		Space type	Energy need	Electric lighting system	Partial expenditure factor	Illumination control				Expenditure factor for lighting	Energy use
						Type	Partial expenditure factors				
							e _{L,O}	e _{L,D}	e _{L,C}		
5	a	I	W _{nd}	Type	e _{L,ES}	[-]	Type	[-]	[-]	E _L	W _{us}
	II	6,8	Efficient, direct	2,36	Automatic	1,13	1,03	1,00	2,74	18,66	
6	b	I	0,6	Existing, direct	6,76	Manual	1,25	1,06	1,11	3,47	23,60
	c	I	HMI, direct II	2,61	Manual	1,00	1,71	1,18	5,24	3,29	
7	d	I	16,6	T16, direct III	2,50	Automatic	1,00	1,28	1,00	3,20	2,01
	a	I	SON, direct I	1,39	Manual	1,00	1,00	1,18	1,64	27,17	
7	b	I	16,6	HMI, direct II	2,61	Manual	1,00	1,00	1,18	3,07	50,94
	d	I	Existing, direct	6,76	manual	1,00	1,00	1,18	7,95	132,10	

6.7.4 Approach to expenditure factors for lighting systems

The systematic evaluation approach below is intended to enhance the understanding of the concept of expenditure factors regarding the introduction and application in practice.

Distinction of the evaluation systematics with regard to calculation procedures

The expenditure factor for lighting correlates the parameters that were determined using calculation procedures to determine the energy need for lighting. Hence, it has no influence on the formal calculation of the energy need for lighting. The application of this systematic evaluation approach enables planners to perform a quick analysis and (if necessary) optimization of the energy flows (or of the required energy input) in the lighting sector, separately for the various technical components of lighting systems.

Scope of evaluation

As illustrated in Figure 4, building-specific influences (like architectural design and boundary conditions for use) are described by means of equal utilization factors (space geometry, space reflectance), daylight availability (facade design, climate, location); requirements pertaining to the visual task, times of usage, relative absence, and the influence of usage on the maintenance of lighting systems are considered both when determining the energy reference value (net energy) and the planned energy target value (delivered energy). In this way they compensate each other and are thus not eligible for evaluations which use the expenditure factor. Different technologies, however, can be directly compared with each other by comparing the expenditure factors. In this way, the partial expenditure factors $e_{L,ES}$, $e_{L,O}$, $e_{L,D}$ and $e_{L,C}$ (see Figure 4), only describe how efficiently the technical systems actually utilize the given potential, which is expressed by the net energy. They do not provide any information about the technical quality of a lighting system or its impact in the respective room.

The amount of net energy itself (and with this, the amount of delivered energy that is coupled to this) can be influenced and optimized at least partially, for instance by designing the room reflectance or room geometries that are appropriate under aspects of lighting.

Absolute values of expenditure factors and comparison to other technical building systems

Due to the required conventions underlying the energy evaluation of light and lighting (reference luminous efficacy and reference luminous intensity distribution) absolute values for expenditure factors are obtained, which are specific to lighting and cannot be directly compared with other technical building services. Investigations of different zones of buildings and technical lighting equipment found expenditure factors to range between 1,6 and 40,2 (see Table 10). It should be noted here that real expenditure factors at present can hardly ever approach a value of $e_{L,ES} = 1$, on account of the convention of $\eta_L = 140 \text{ lm/W}$. This situation may however soon change due to the still rapidly rising efficiency of LED lamps. The dynamic development regarding the values of expenditure factors and with this the energy efficiency of lighting technologies are subject to strong variations.

For comparison: in the sector of heating technology, expenditure factors are generally lower and they are characterized by a less dynamic development regarding the values. For typical constellations using radiators as heat emission systems, at a given ratio of flow/ return temperature of 55 °C / 45 °C, the following values result:

- Heat generation by condensing boiler: values of approximately 1,4,
- By an electric ground-to-water heat pump or by CHP district heat: values of 0,9.
- Expenditure factors < 1 can be achieved e.g. due to use of efficient heat pumps.

Comparison with established efficiency figures in the lighting sector

In the sector of general lighting, energy efficiency has often been evaluated merely on the basis of the installed power per unit area of electric lighting P_{inst} [W/m^2], due to the practical concentration on planning electric installations, exclusively.

The installed power P_{Inst} is an absolute value, not a relative one. It has therefore no specific point of reference. Expert knowledge is required to be able to assign an installed power of 14 W/m^2 for the 'office' type of use. It cannot be related to the technically achievable level/standard. By contrast, a relative characteristic (for instance an expenditure factor of $e_{\text{L,ES}} = 1,6$) directly indicates that the requirements on the lighting situation will be fulfilled by a lighting system, which exceeds by 60 % the energy demand of a system with optimum energy performance.

The energy need is determined by determining the effective operating time t_{eff} and weighting with the installed power. t_{eff} includes the impact of lighting control, but does not indicate these separately. Thanks to the expenditure factor, the energy impact of lighting control under building-specific conditions now becomes immediately visible.

6.7.5 Expenditure factors for lighting systems calculation

The concept of expenditure factors is described in 6.7. Regarding this quick calculation method 2, the following simplifications can be derived for the partial expenditure factor for constant illuminance control $e_{\text{L,C}}$ and the partial expenditure factor for daylight dependent lighting control $e_{\text{L,D}}$, based on the simplifications described in 6.7.2.4:

- Simplified derivation of the partial expenditure factor for constant illuminance control $e_{\text{L,C}}$:

$$e_{\text{L,C}} = \frac{1}{1 - \frac{1}{2}(1 - MF)} \quad \text{with no constant illuminance control} \quad (4)$$

$$e_{\text{L,C}} = 1 \quad \text{with constant illuminance control} \quad (5)$$

- Simplified derivation of the partial expenditure factor for daylight dependent lighting control $e_{\text{L,D}}$:

$$e_{\text{L,D}} = \frac{A_{\text{D}} \left[t_{\text{Day}} \cdot (1 - F_{\text{D,S}} \cdot 0,52) + t_{\text{Night}} \right] + A_{\text{ND}} (t_{\text{Day}} + t_{\text{Night}})}{A_{\text{D}} \left[t_{\text{Day}} \cdot (1 - F_{\text{D,S}}) + t_{\text{Night}} \right] + A_{\text{ND}} (t_{\text{Day}} + t_{\text{Night}})} \quad (6)$$

The calculation of the partial expenditure factor for the electric lighting system $e_{\text{L,ES}}$, follows method c), as given in 6.5 in the standard.

7 Method 2 – Quick calculation of the energy required for lighting

7.1 Rationale

This method is quick and simple as it employs approximation procedures for the calculation of the required installed load and uses default data for the impact assessment of the lighting controls. The output of the method will be as in 5.2.1 of the standard but gives budget estimated values that in general are likely to be higher than those obtained from the comprehensive design process. The method is particularly useful for new and refurbishment buildings during concept design and feasibility study stage. The energy requirement values should be recalculated with real data when the comprehensive lighting system design has been completed.

7.2 Time steps

Yearly - Taken as 8 760 h.

7.3 Assumptions

Intended lighting solution/system has been identified.