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Calculation of the impact of daylight utilization on the net and final energy demand for lighting

Calcul de l'effet d'utiliser la lumière du jour à la demande énergétique net et finale pour l'éclairage

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Foreword

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The committee responsible for this document is ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*.

Introduction

This International Standard is part of a set of standards allowing to rate the overall energetic performance of buildings. Facades and rooflights have a key impact on the building's energy balance. This International Standard supports the daylighting and lighting-energy-related analysis and optimization of facade and rooflight systems. It was therefore specifically devised to establish conventions and procedures for the estimation of daylight penetrating buildings through vertical facades and rooflights, as well as on the energy consumption for electric lighting as a function of daylight provided in indoor spaces.

Calculation of the impact of daylight utilization on the net and final energy demand for lighting

1 Scope

This International Standard defines the calculation methodology for determining the monthly and annual amount of usable daylight penetrating non-residential buildings through vertical facades and rooflights and the impact thereof on the energy demand for electric lighting. This International Standard can be used for existing buildings and the design of new and renovated buildings.

This International Standard provides the overall lighting energy balance equation relating the installed power density of the electric lighting system with daylight supply and lighting controls (proof calculation method).

The determination of the installed power density is not in the scope of this method, neither are controls relating, for instance, to occupancy detection. Provided the determination of the installed power density and control parameters using external sources, the internal loads by lighting and the lighting energy demand itself can be calculated. The energy demand for lighting and internal loads by lighting can then be taken into account in the overall building energy balance calculations:

— heating;

— ventilation;

— climate regulation and control (including cooling and humidification);

— heating the domestic hot-water supply of buildings.

For estimating the daylight supply and rating daylight-dependent artificial lighting control systems, a simple table-based calculation approach is provided. The simple method describes the division of a building into zones as required for daylight illumination-engineering purposes, as well as considerations on the way in which daylight supplied by vertical facade systems and rooflights is utilized and how daylight-dependent lighting control systems effect energy demand. Dynamic vertical facades with optional shading and light redirection properties are considered, i.e. allowing a separate optimization of facade solutions under direct insolation and under diffuse skies. For rooflighting systems standard, static solutions like shed rooflights and continuous rooflights are considered. The method is applicable for different latitudes and climates. For standard building zones (utilizations), operation times are provided.

For detailed computer-based analysis (comprehensive calculation), minimum requirements are specified.

To support overall building performance assessment, additional daylight performance indicators on the overall building level are provided.

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.

CIE S 017/E:2011, *ILV: International Lighting Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in CIE S 017/E:2011 ILV apply.

3.1
ballast
unit inserted between the supply and one or more discharge lamps, which by means of inductance, capacitance, or a combination of inductance and capacitance, serves mainly to limit the current of the lamp(s) to the required value

3.2
control system
various types of electrical and electronic systems including the following:

— systems used to control and regulate;

— systems to protect against solar radiation and/or glare;

— artificial lighting in relation to the currently available daylight;

— systems used to detect and record the presence of occupants

3.3
daylight factor
D
ratio of the illuminance at a point on a given plane due to the light received directly and indirectly from a sky of assumed or known luminance distribution to the illuminance on a horizontal plane due to an unobstructed hemisphere of this sky, where the contribution of direct sunlight to both illuminances is excluded

[SOURCE: CIE S 017/E:2011 ILV, modified]

Note 1 to entry: CIE S 017/E:2011 defines the unit as 1. However, daylight factor is in practice, usually presented in percent values.

3.4
electrical power of artificial lighting system
P
the total electrical power consumption of the lighting system in the considered space

3.5
illuminance
E
quotient of the luminous flux dΦ incident on an element of the surface containing the point, by the area dA of that element

[SOURCE: CIE S 017/E:2011 ILV, modified]

Note 1 to entry: Unit: lx = lm × m^{-2}.

3.6
lamp
source made to produce optical radiation, usually visible

3.7
light reflectance
ratio of the reflected luminous flux to the incident luminous flux in the given conditions

Note 1 to entry: Unit: 1.

3.8
light transmittance
ratio of the transmitted luminous flux to the incident luminous flux in the given conditions

Note 1 to entry: Unit: 1.

3.9
luminaire
apparatus which distributes, filters, or transforms the light transmitted from one or more lamps and which includes, except the lamps themselves, all the parts necessary for fixing and protecting the lamps and, where necessary, circuit auxiliaries together with the means for connecting them to the electric supply

[SOURCE: CIE S 017/E:2011 ILV]

3.10
luminous exposure
quotient of quantity of light $\mathrm{d}Q_\mathrm{v}$ incident on an element of the surface containing the point over the given duration, by the area $\mathrm{d}A$ of that element

Note 1 to entry: Unit: lx × s = lm × s × m^{-2}.

3.11
luminous flux
Φ
quantity derived from the radiant flux, Φ_e, by evaluating the radiation according to its action upon the CIE standard photometric observer

Note 1 to entry: Unit: lm.

3.12
maintained illuminance
$\bar{E}_\mathrm{m}$
value below which the average illuminance over the specified surface is not allowed to fall

Note 1 to entry: Unit: lx = lm × m^{-2}.

3.13
obstruction
anything outside the window which prevents the direct view of part of the sky

3.14
rooflight
daylight opening on the roof or on a horizontal surface of a building

3.15
task area
partial area in the work plane in which the visual task is carried out

[SOURCE: CIE S 017/E:2011 ILV]

3.16
visual task
visual elements of the work being done

[SOURCE: CIE S 017/E:2011 ILV]

4 Symbols, indices, and abbreviated terms

For the purposes of this document, the following symbols and units apply.

4.1 Symbols

	Quantity	Unit
τ	light transmittance	—
ρ	light reflectance	—
Φ	luminous flux	lm
η	efficiency	—
Q	energy	kWh
γ	angle, geographical latitude	°
δ	declination of the sun	°
a	depth	M
A	area	m^2
b	width	M
bf	occupancy factor	—
C	correction factor	—
D	daylight factor	—
$\bar{D}$	mean daylight factor	—
E	illuminance	lx
$\bar{E}_m$	maintained illuminance	lx
f, F	factors	—
g	g-value	—
H	luminous exposure	lxh
h	height	m
I	index	—
k	space index	—
k	correction factor	—
J	counter for number of areas being evaluated	—
N	counter for number of zones	—
p	area-specific power	W/m^2
t	time	H
U	U-value of glazing system	W/m^2K
v	distribution key	—
wi	light-well index	—

4.2 Indices

A	absence	ND	no daylight
At	atrium	Night	night-time
c	control	O	occupancy
Ca	carcass opening	R	room
D	daylight	rel	relative
Day	day-time	Rd	room depth, space depth
dir	direct	s	transparent or translucent surface of the daylight aperture
D65	standard lightsource D65	s	supply
e	energic quantity	SA	sun-shading activated
eff	effective, root-mean-square	Sh	shading, obstruction
ext	external, outdoors	SNA	sun-shading not activated
GDF	glazed curtain wall, glazed double facade	start	start
glob	global	sunrise	sunrise
hf	horizontal fin or projection	t	building use (operating) time
i,j,n	serial counter indices	Ta	task area
In	internal courtyard	Tr	transparency
Li	lintel	u	lower
lsh	linear shading	usage	usage
max	maximum	v	visual quantity
mth	monthly	vf	vertical fin or projection

5 Proof calculation method

5.1 Energy demand for lighting as function of daylight

The final energy demand for lighting purposes is $Q_{\mathrm{l,f}}$ to be determined for a total of N building zones which can be subdivided into J evaluation areas:

$$Q_{\mathrm{l,f}} = \sum_{n=1}^{N} \sum_{j=1}^{J} Q_{\mathrm{l},f,n,j} \tag{1}$$

The energy demand of any one evaluation area j is calculated by applying Formulae (2) and (3).

$$Q_{\mathrm{l,n},j} = p_j\, F_{\mathrm{c},j} \left[A_{\mathrm{D},j} \left(t_{\mathrm{eff,Day,D},j} + t_{\mathrm{eff,Night},j} \right) + A_{\mathrm{ND},j} \left(t_{\mathrm{eff,Day,ND},j} + t_{\mathrm{eff,Night},j} \right) \right] \tag{2}$$

where

$$A_j = A_{\mathrm{D},j} + A_{\mathrm{ND},J} \tag{3}$$

applies to the total area of the respective evaluation area, and where

$Q_{l,f}$ is the final energy demand for lighting;

N is the number of zones;

J is the number of areas;

$F_{c,j}$ factor relating to the usage of the total installed power when constant illuminance control is in operation in the room or zone;

p_j is the specific electrical evaluation power of area j;

A_j is the floor area of area j;

$A_{D,j}$ is that part of area j which is lit by daylight;

$A_{ND,j}$ is that part of area j which is not lit by daylight;

$t_{eff,Day,D,j}$ is the effective operating time of the lighting system, during day-time, in area j which is lit by daylight;

$t_{eff,Day,ND,j}$ is the effective operating time of the lighting system, during day-time, in area j which is not lit by daylight;

$t_{eff,Night,j}$ is the effective operating time of the lighting system, during night-time, in area j.

The effective operating time, during day-time, in an area which is lit by daylight is calculated using Formula (4).

$$t_{eff,Day,D,j} = t_{Day,n} F_{D,j} F_{O,j} \tag{4}$$

The effective operating time, during day-time, in an area which is not lit by daylight is calculated using Formula (5).

$$t_{eff,Day,ND,j} = t_{Day,n} F_{O,j} \tag{5}$$

where

$t_{Day,n}$ is the operating time of zone n during day-time, as defined in 5.3;

$F_{D,j}$ is the part-utilization factor to account for the illumination by daylight in the evaluation area j as defined in 5.6;

$F_{O,j}$ is the part-utilization factor to account for the presence of persons (occupancy) in the evaluation area j as defined in 5.7.

Formula (6) is used to calculate the effective operating time during night-time.

$$t_{eff,Night,j} = t_{Night,n} F_{O,j} \tag{6}$$

where

$t_{Night,n}$ is the operating time of zone n during night-time, as defined in 5.3.

Figure 1 illustrates the order in which the individual steps of the calculations are carried out.

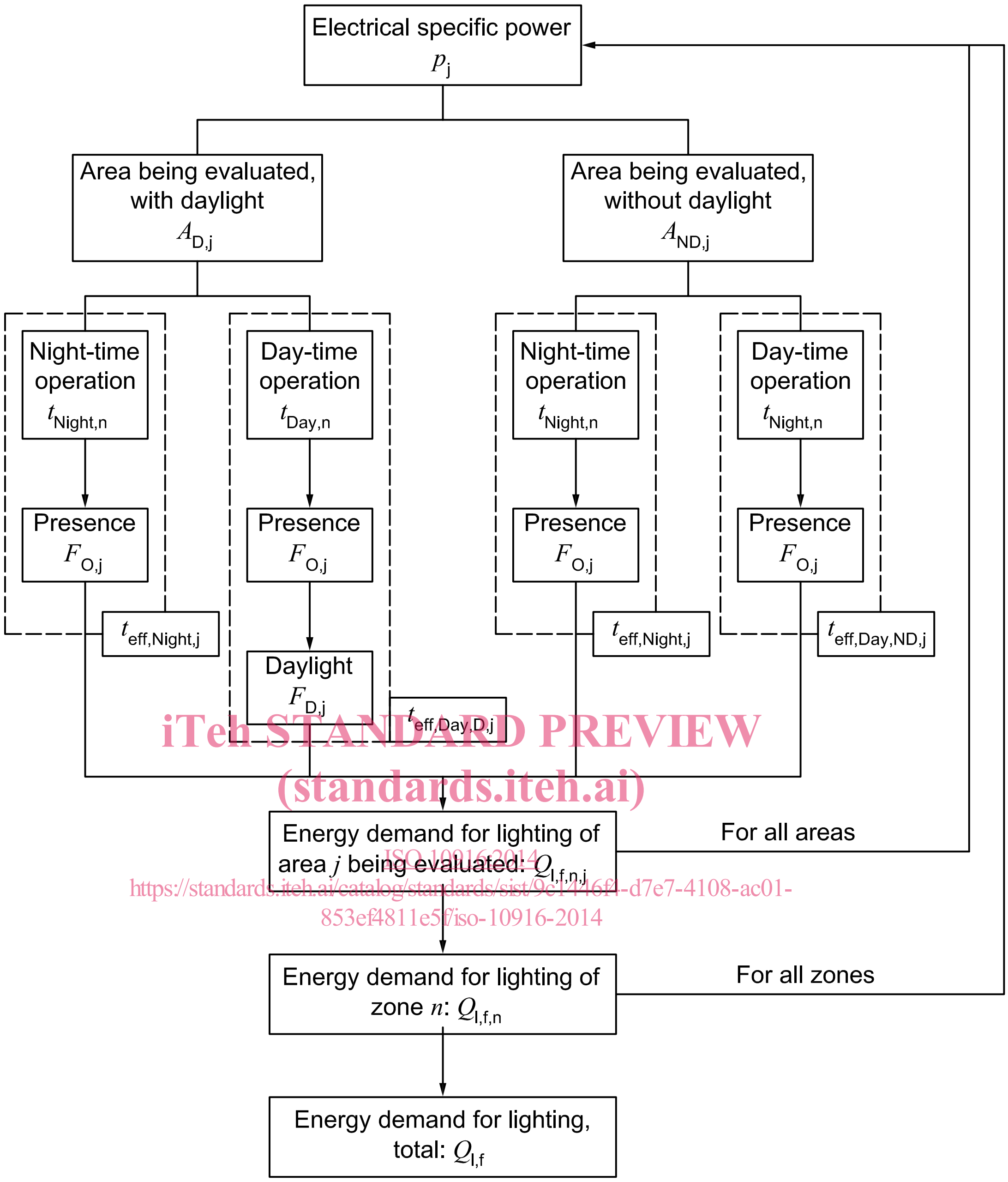

Figure 1 — Flowchart showing calculation of the energy demand for lighting

5.2 Subdivision of a building into zones

The final energy demand for lighting is calculated for all building zones N. The building zones are to be defined in accordance with the zoning boundary conditions as requested by other criteria like utilization of spaces and technical requirements.

It can be necessary to subdivide a building zone n into J evaluation areas to determine the final energy demand for lighting. This subdivision can be necessary due to differences in the boundary conditions (e.g. technical design of the artificial lighting system, lighting control systems, characteristics of the facades).

From practical experience, a simplification rule can be recommended: One and the same boundary condition can be assumed to apply for an entire building zone or an evaluation area if the corresponding input parameter applies to at least 75 % of the area being evaluated. Input parameters of the remaining parts (e. g. window areas) assigned to the dominating areas are not taken into account in the calculations.

The specific energy demand is calculated for that part of the evaluation area which occupies at least 75 % of the total area and is then assumed to apply to the total area.

5.3 Operating time

The times during which the areas of a zone being evaluated are used are subdivided into intervals $t_{\mathrm{Day},n}$ during which daylight is available, and intervals $t_{\mathrm{Night},n}$ without daylight. The operating time t_n is equal to $t_{\mathrm{Day},n} + t_{\mathrm{Night},n}$. Day-time is thus the time span between sunrise and sunset. Annual daylight hours and night hours are defined in relation to the different utilization profiles given in Annex A. For operating times which do not match the cases listed in the tables, the values shall be determined separately.

5.4 Artificial lighting

The specific electrical power of the artificial light installation p_j can be obtained by, for instance, using standard lighting design software, as provided by luminaire manufacturers. Simplified methods as defined in DIN V 18599-4[2] can as well be employed.

5.5 Constant illuminance control

When constant illuminance control is in operation in the zone or evaluation area, the installed power will be lowered by a factor F_{c}.

5.6 Daylight

In zones which have windows or rooflights, daylight can contribute to the amount of the luminous exposure required. Therefore, this proportion of the required light does not need to be provided by the artificial lighting system.

The daylight available in the outdoor environment depends on the geographical location, the climatic boundary conditions, the time of day, and the season. Furthermore, the daylight availability in a building also depends on the external building structure and surrounding buildings, spatial orientation, and the technical specifications of the facades and internal spaces (rooms). Since the available daylight varies with the time of day and the season, the lighting energy substitution potential is dynamic and therefore has a dynamic effect on the overall energy balance (for heating, cooling, and air-conditioning) of the building.

The daylight dependency factor $F_{\mathrm{D},j}$ used to account for lighting of an area j by daylight is defined as

$$F_{\mathrm{D},j} = 1 - F_{D,\mathrm{s},j}\, F_{D,\mathrm{c},j} \tag{7}$$

where

$F_{\mathrm{D,s},j}$ is the daylight supply factor;

$F_{\mathrm{D,c},j}$ is the factor representing the effect of the daylight-responsive control system.

The daylight supply factor $F_{\mathrm{D,s},j}$ accounts for the amount of lighting of the evaluation area j by daylight. This factor describes the relative proportion of the light needed for the visual task provided by daylight within the reference time interval at the point where the illuminance is measured (control point). When determining this factor, the type of lighting control system shall be taken into consideration. The factor corresponds to the relative luminous exposure as, for instance, defined in DIN 5034-3,[4] also referred to as "daylight autonomy". The factor $F_{\mathrm{D,c},j}$ additionally accounts for the efficiency of the lighting control system in using the available daylight to achieve the required luminous exposure level in the area j. The daylight dependency factor $F_{\mathrm{D},j}$ which takes the daylight illumination into consideration can be determined for any given time interval (e. g. year, month, hour).

Annex A comprises simplified approaches to calcutate $F_{D,S,j}$ for vertical facades (A.3) and rooflights (A.4) and to obtain tabulated values for $F_{D,c,j}$. Annex B contains specifications for using comprehensive, detailed computer-based tools to calculate $F_{D,j}$.

5.7 Occupancy dependency factor $F_{O,n}$

The occupancy dependency factor $F_{O,n}$ for a room or zone correlates the time when a space is occupied with the efficiency to benefit from this potential by either manual or automatic switching. Parametrizations of $F_{O,n}$ might, for instance, be found in DIN V 18599-4[2] and EN 15193.[6]

6 Daylight Performance Indicator

To judge the overall daylight performance of a building or a building design and to compare different buildings or building designs, integral daylight performance indicators are helpful. Annex C gives definitions and explains their application.

