International Standard

ISO/CIE 10916

First edition
2024-11

Light and lighting — Energy performance of lighting in buildings — Calculation of the impact of daylight utilization

Lumière et éclairage — Performance énergétique de l'éclairage des bâtiments — Calcul de l'impact de l'utilisation de la lumière du jour

Reference number
ISO/CIE 10916:2024(en)

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Published in Switzerland

Contents

Page

Foreword

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This document was prepared by Technical Committee ISO/TC 274, *Light and lighting,* in collaboration with the International Commission on Illumination (CIE).

This first edition of ISO/CIE 10916 cancels and replaces ISO 10916:2014, which has been technically revised.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document is part of a set of standards which allows users to rate the overall energetic performance of buildings. Facades and rooflights have a key impact on the building's energy balance. This document supports daylighting and lighting-energy-related analysis and optimization of facade and rooflight systems. It is 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.

Light and lighting — Energy performance of lighting in buildings — Calculation of the impact of daylight utilization

1 Scope

This document 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 document is applicable for existing buildings and the design of new and renovated buildings.

This document 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 electric 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 affect 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 analysis, an approach to calculate the effect of daylight on the lighting energy demand on an hourly or sub-hourly basis is provided. Unlike the simple table-based annual calculation approach, which is regression based, this method relies on an emulation concept. Relevant quantities are modelled explicitly and are then interacting directly with sensors, actuators and functional elements of the building automation and control system (BACS) or are triggering user interaction. By this approach, model configuration and parametrization from the design stage can seamlessly be used in the BACS configuration.

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

CIE S 017:2020, *ILV: International Lighting Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in CIE S 017, and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

CIE maintains a terminology database for use in standardization at the following address:

— e-ILV: available at https://cie.co.at/e-ilv

3.1
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;

— electric lighting in relation to the currently available daylight;

— systems used to detect and record the presence of occupants

3.2
daylight factor
D
quotient 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 and 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

Note 1 to entry: Glazing, dirt effects, etc. are included.

Note 2 to entry: When calculating the lighting of interiors, the contribution of direct sunlight has to be considered separately.

Note 3 to entry: CIE S 017:2020 defines the unit as 1. However, daylight factor is in practice, usually presented in percent values.

Note 4 to entry: The term daylight factor is normally used when considering an overcast sky as sky type 1 or 16 in ISO 15469.

[SOURCE: CIE S 017:2020, 17-29-121, modified — Notes 3 to 5 deleted, new Notes to entry 3 and 4 added]

3.3
electrical power of electric lighting system
P
total electrical power consumption of the lighting system in the considered space

3.4
illuminance
E
density of incident luminous flux with respect to area at a point on a real or imaginary surface

$$E = \frac{d\Phi_v}{dA},$$

where

Φ_v is luminous flux;

A is the area on which the luminous flux is incident

Note 1 to entry: The illuminance is expressed in lux ($lx = lm \cdot m^{-2}$).

[SOURCE: CIE S 017:2020, 17-21-060, modified — Notes 1, 2, 4 and 5 deleted.]

3.5
insolation
incidence of solar radiation on a surface or body

3.6
luminaire
apparatus which distributes, filters or transforms the light transmitted from at least one source of optical radiation and which includes, except the sources themselves, all the parts necessary for fixing and protecting the sources and, where necessary, circuit auxiliaries together with the means for connecting them to the power supply

[SOURCE: CIE S 017:2020, 17-30-001, modified — Notes deleted.]

3.7
luminous exposure
H_v
H
density of incident luminous energy with respect to area at a point on a real or imaginary surface

$$H_v = \frac{dQ_v}{dA}$$

where

Q_v is the luminous energy;

A is the area on which the luminous energy is incident.

Note 1 to entry: The luminous exposure is expressed in lux second ($lx{\cdot}s = lm{\cdot}s{\cdot}m^{-2}$) or lux hours ($lx\ h = lm{\cdot}h{\cdot}m^{-2}$).

[SOURCE: CIE S 017:2020, 17-21-072, modified — Notes 1, 2, 3, 5 and 6 deleted, added possibility to express in lux hours.]

3.8
luminous flux
Φ
Φ_v
change in luminous energy with time

$$\Phi_v = \frac{dQ_v}{dt}$$

where

Q_v is the luminous energy emitted;

t is time.

Note 1 to entry: The luminous flux is expressed in lumen (lm).

[SOURCE: CIE S 017:2020, 17-21-039, modified— Notes 1, 2, 3, 5 and 6 deleted.]

3.9
maintained average illuminance
$\bar{E}_m$
value below which the average illuminance over the specified surface is not allowed to fall

Note 1 to entry: In specific contexts of this document the maintained average illuminance can in limit case be the maintained point illuminance

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

3.10
shading
anything inside, in between or outside the window which prevents the direct view of part of the sky

Note 1 to entry: Shading can be manually operated or automatic and can as well be moveable or fixed.

Note 2 to entry: For example shutters, external or internal blinds.

3.11
daylight opening
any area in the building envelope that is capable of admitting daylight to an interior

3.12
rooflight
daylight opening (3.11) on the roof or on a horizontal surface of a building

3.13
task area
partial area in the work place in which the visual task is carried out

[SOURCE: CIE S 017:2020, 17-29-171, modified — Notes deleted.]

3.14
visual task
visual elements of the work being done

[SOURCE: CIE S 017:2020, 17-22-084, modified — Notes deleted.]

4 Symbols, indices, and abbreviated terms

4.1 Symbols

	Quantity	Unit
Φ	luminous flux	lm
Q	energy	kWh
γ	angle, geographical latitude	°
δ	declination of the sun	°
a	depth	m
A	area	m^2
b	width	m
D	daylight factor	—
$\bar{D}$	mean daylight factor	—
E	illuminance	lx
E_e	irradiance	$W \cdot m^{-2}$
$\bar{E}_m$	maintained illuminance	lx
f, F	factors	—

	Quantity	Unit
H	luminous exposure	lx h
h	height	m
I	index	—
$I_{\mathrm{Tr},j}$	Transparency index	—
$I_{\mathrm{RD},j}$	Space depth index	—
$I_{\mathrm{Sh},j}$	Shading index	—
$I_{\mathrm{Sh,lsh}}$	Linear shading, correction factor	—
$I_{\mathrm{Sh,hf}}$	Horizontal projections, correction factor	—
$I_{\mathrm{Sh,vf}}$	Vertical projections, correction factor	—
k_{si}	space index	—
k_{cf}	correction factor	—
t	time	s, h
v	distribution key	—

4.2 Indices and abbreviated terms

A	absence	ND	no daylight
At	atrium	Night	night-time
c	control	O	occupancy
Ca	carcass opening	R, Room	room
D	daylight	rel	relative
Day	day-time	Rd	room depth, space depth
dir	direct	$\mathrm{s_t}$	transparent or translucent surface of the daylight aperture
D65	standard lightsource D65	$\mathrm{s_s}$	supply
e	energy quantity	SA	sun-shading activated
Eff eq	effective, root-mean-square equivalent	Sh	shading, obstruction
ext	external, outdoors	SNA	sun-shading not activated
GDF	glazed curtain wall, glazed double facade	start	start
glob	global	sunrise sunset	sunrise sunset
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 Month	Maximum Month	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 $Q_{l,f}$ to be determined for a total of N building zones which can be subdivided into J evaluation areas:

$$Q_{l,f} = \sum_{n=1}^{N} \sum_{j=1}^{J} Q_{l,f,n,j} \quad (1)$$

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

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

where

$$A_j = A_{D,j} + A_{ND,J} \quad (3)$$

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).

$$t_{eff,Day,D,j} = t_{Day,n} \, F_{D,j} \, F_{O,j} \quad (4)$$

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

$$t_{eff,Day,ND,j} = t_{Day,n} \, F_{O,j} \quad (5)$$

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.

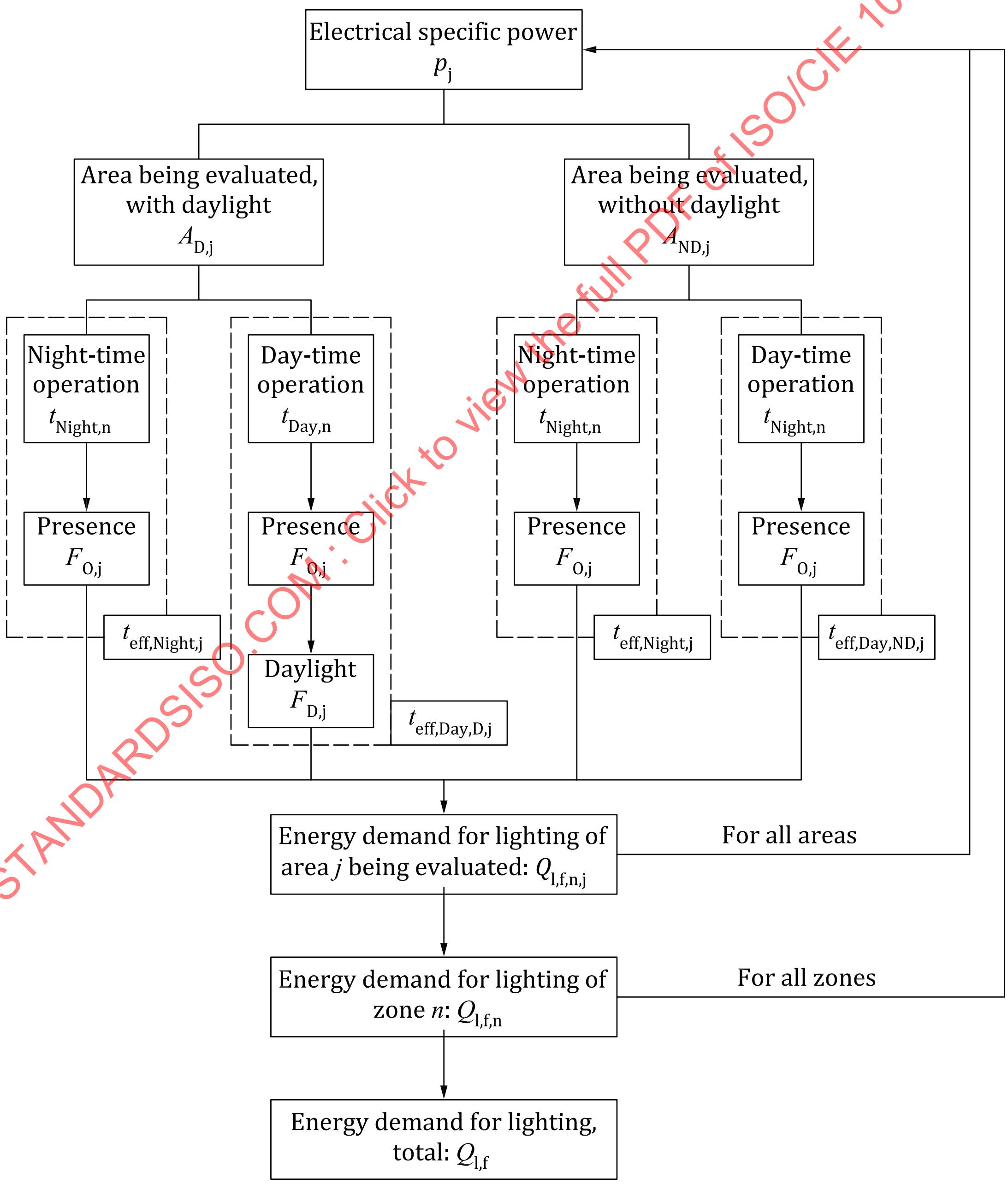


Figure 1 — Flowchart showing calculation of the energy demand for lighting

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 electric lighting system, lighting control systems, characteristics of the facades).

From practical experience, a simplification rule can be recommended: 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 may be determined separately. This may follow the scheme of Table A.21, i.e. specifying the specific data in columns 3, 4, 5 and 6. Data for columns 8 and 9 are separated according to the above described split if the operating time into t_{Day} and t_{Night}.

5.4 Electric lighting

The specific electrical power of the electric 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 ISO/CIE 20086, 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 electric 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

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

where

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

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

The daylight supply factor $F_{D,s,j}$ 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 the ratio of luminous flux by daylight up to the required maintained illuminance to the total luminous flux for the required maintained illuminance over operation time.

NOTE The relative luminous exposure is also referred to as “daylight autonomy”.

The factor $F_{D,c,j}$ 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 $F_{D,j}$ 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 calculate $F_{D,S,j}$ for vertical facades (A.3) and rooflights (A.4) and to obtain tabulated values for $F_{D,c,j}$. Annex B contains a methodology for detailed generally computer-based comprehensive calculations to calculate the effect of daylight on the lighting energy demand on an hourly or sub-hourly basis.

A calculation example each for daylight penetration through a vertical facade and a rooflight is given in Annex D.

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 potential energy savings by either manual or automatic switching. Parametrizations of $F_{O,n}$ can, for instance, be found in ISO/CIE 20086.

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.

Annex A
(informative)

Simple calculation method

A.1 General

This Annex specifies a simplified approach to calculate the effect of daylight on the lighting energy demand on monthly and annual bases. The method involves the following stages to obtain, according to Clause 5, the daylight dependent quantities $F_{D,n,j}$, $t_{Day,n,j}$ and as a function thereof $t_{eff,Day,n,j}$, as also depicted in Figure A.1:

— A.2 contains a scheme of how to subdivide the zone to be evaluated into area sections which receive daylight and those which do not;

— A.3 specifies a procedure on how to determine the daylight supply factor $F_{D,S,n,j}$ for spaces lit by vertical facades;

— A.4 specifies a procedure on how to determine the daylight supply factor $F_{D,S,n,j}$ for spaces lit by rooflights;

— A.5 specifies a procedure on how to rate daylight responsive control systems described by the parameter $F_{D,C,n,j}$;

— A.6 describes how to convert annual values into monthly values of $F_{D,n,j}$;

— A.7 provides a procedure to determine day- and night-time hours;

— A.8 provides a list of precalculated day- and night-time hours for 41 different utilization types of building spaces.

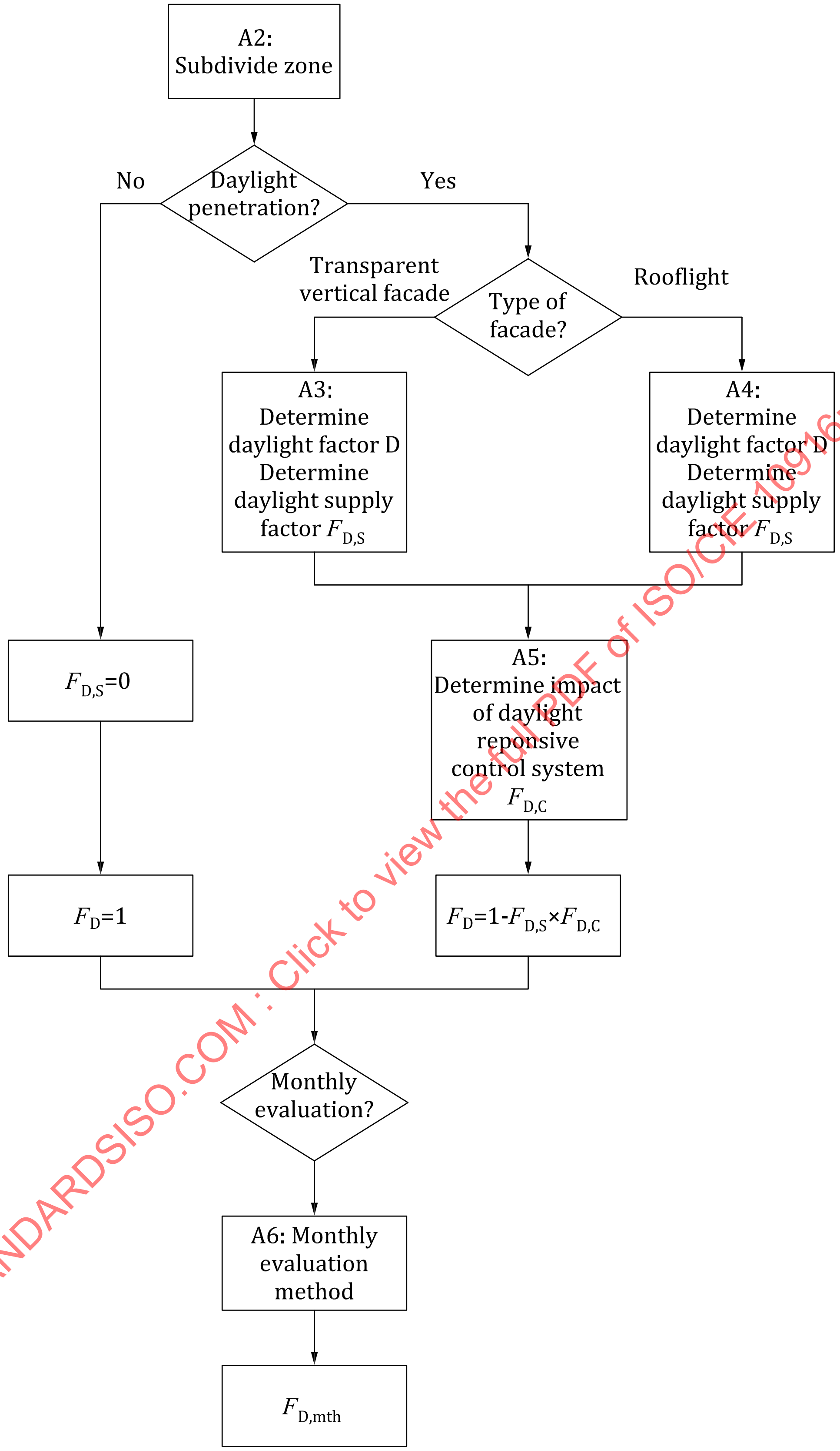


Figure A.1 — Flowchart illustrating the simplified approach

For the determination of the daylight supply factor $F_{D,S,n,j}$, as well for a vertical facade (A.3) as for rooflights (A.4), Figure A.2 shows the applied three-stage approach:

— Stage 1: Use of a simple criterion approximating the daylight factor to classify the type of daylight availability on the basis of the geometrical parameters of the building zone being evaluated. This assumes a combination of standard reflectances, $\rho_F = 0{,}2$ for the floor, $\rho_W = 0{,}5$ for the walls, and $\rho_C = 0{,}7$ for the ceiling. The reflectance of the external surroundings is assumed to be 0,2. Instead of using these approximations, a more detailed determination of the daylight factor can be carried out for more complicated space geometries and other reflectance values using a computer program.

— Stage 2: Describe the facade characteristics.

— Stage 3: Determine the annual amount of daylight available on the basis of the daylight supply classification of the building zone and the facade characteristics as a function of location and climate.

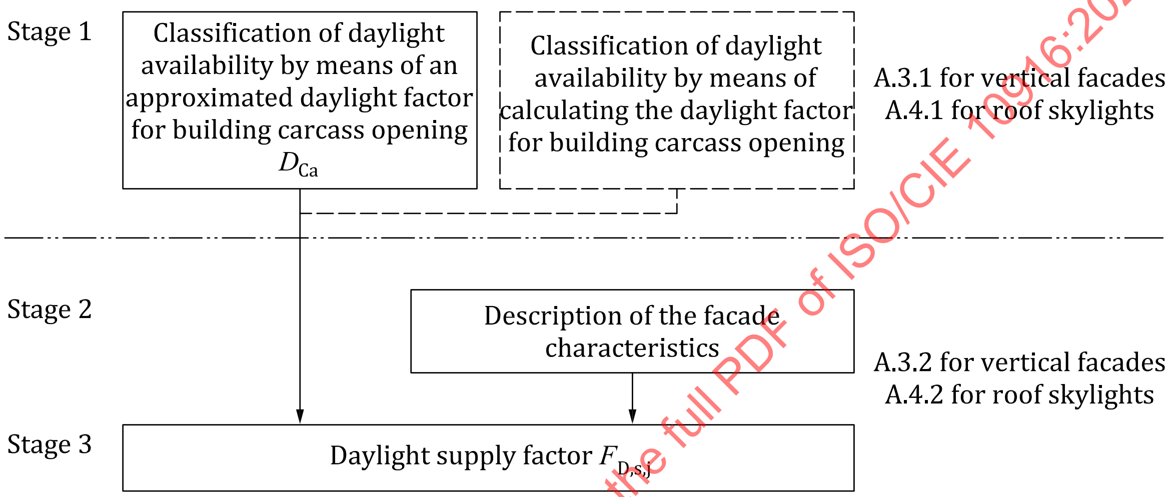


Figure A.2 — Three-stage approach to determining the daylight supply factor $F_{D,s,j}$

A.2 Building segmentation: spaces benefiting from daylight

Evaluation zones which are illuminated by daylight entering via facades or rooflights shall be subdivided into a daylight-lit area $A_{D,j}$ and an area $A_{ND,j}$ which is not illuminated by daylight. For simplified estimate calculations, the more favourable respective lighting conditions can be assumed to apply in cases where one area is illuminated by daylight entering via several facades or via a facade and rooflights. Alternatively, it is also possible in these areas to determine the daylight factor according to A.3 and A.4 by superposition. This can nevertheless only be applied for areas being lit by only one type of daylight aperture (either vertical facade or rooflight). Figure A.3 shows the impact of a facade opening on the daylight area for vertical facades.

— Depth and width of the daylight area lit by vertical facades

The maximum possible depth $a_{D,max,j}$ of the area $A_{D,j}$ lit by daylight entering via a facade is calculated using Formula (A.1).

$$a_{D,max,j} = 2{,}5 \times (h_{Li} - h_{Ta}) \tag{A.1}$$

where

$a_{D,max,j}$ is the maximum depth of the daylight area;

h_{Li} is the height of the window lintel above the floor;

h_{Ta} is the height of the task area above the floor.

In this case, the maximum depth $a_{D,max}$ of the daylight area is calculated from the inner surface of the external wall and at right angles to the reference facade. If the real depth of the area being evaluated is less than the calculated maximum depth of the daylight area, then the total area depth is considered to be the depth of the daylight area a_D. The a_D value can also be assumed to be equal to the real depth of the area being evaluated if the real area depth is less than 1,25 times the calculated maximum daylight area depth.

The partial area $A_{D,j}$ which is lit by daylight within the area j is thus calculated as follows:

$$A_{D,j} = a_D \, b_D \tag{A.2}$$

where

a_D is the depth of the daylight area;

b_D is the width of the daylight area.

The width b_D of the daylight area normally corresponds to the facade width on the inner surface of the building zone or the area being evaluated. Internal walls can be overmeasured (i.e. their thickness ignored) to keep the equations simple. If windows only constitute a part of the facade, then the width of the daylight area associated with this facade is equal to the width of the section which has windows, plus half the depth of the daylight area.

— Depth of the daylight area lit by rooflights

Areas to be evaluated having rooflights evenly distributed all over the roof area are always deemed to be lit by daylight. In the case of individual or single rooflights and at the boundaries of areas which have evenly distributed skylights, those parts of the area which are within a distance of

$$a_{D,max} \leq 2 \times \left(h_{R,j} - h_{Ta,j} \right) \tag{A.3}$$

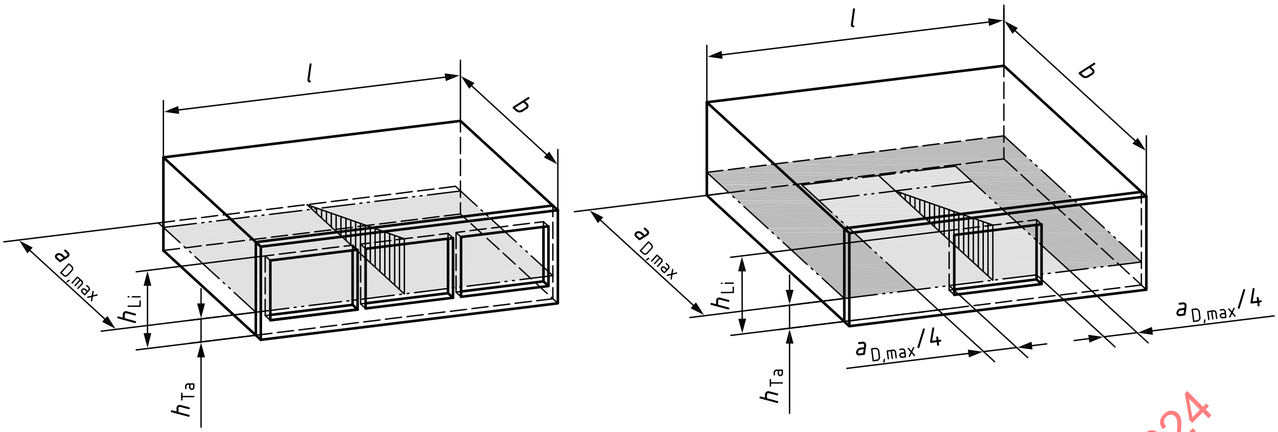
from the edge of the nearest skylight are deemed to be lit by daylight,

where $h_{R,j}$ is the clear ceiling height of the area (room) which has a skylight.

For all parts of the area under evaluation which are not lit by daylight, the factor $F_{D,j}$ is equal to 1. Figure A.4 shows the impact of a roof opening on the daylight area for rooflights.

— Distinction between vertical facades and rooflights

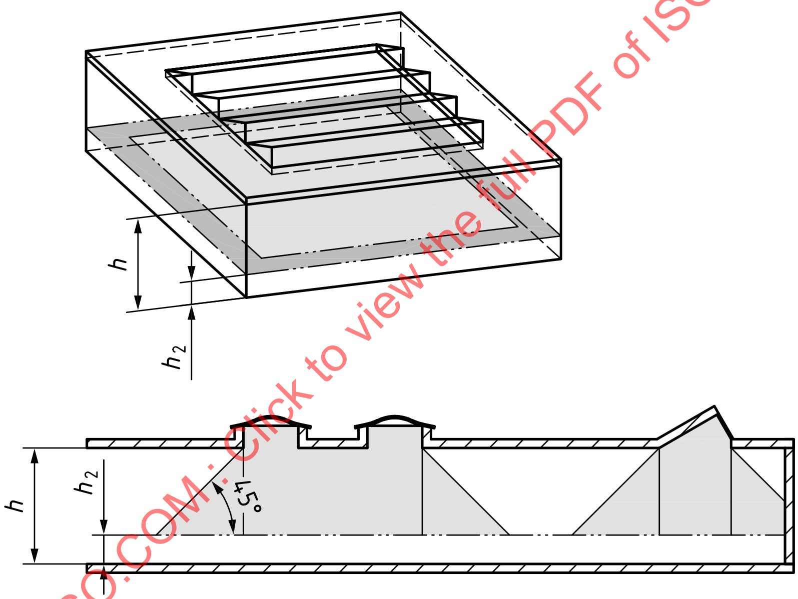
In case of doubt as to whether a specific opening or aperture is to be evaluated as being a window or a rooflight, all such openings of which the entire glazed areas are above the ceiling of the space under consideration are deemed to be rooflights. Figure A.5 shows the superposition and penetration of daylight areas for vertical facades and rooflights.



Key

(light grey)	A_D
(dark grey)	A_{ND}

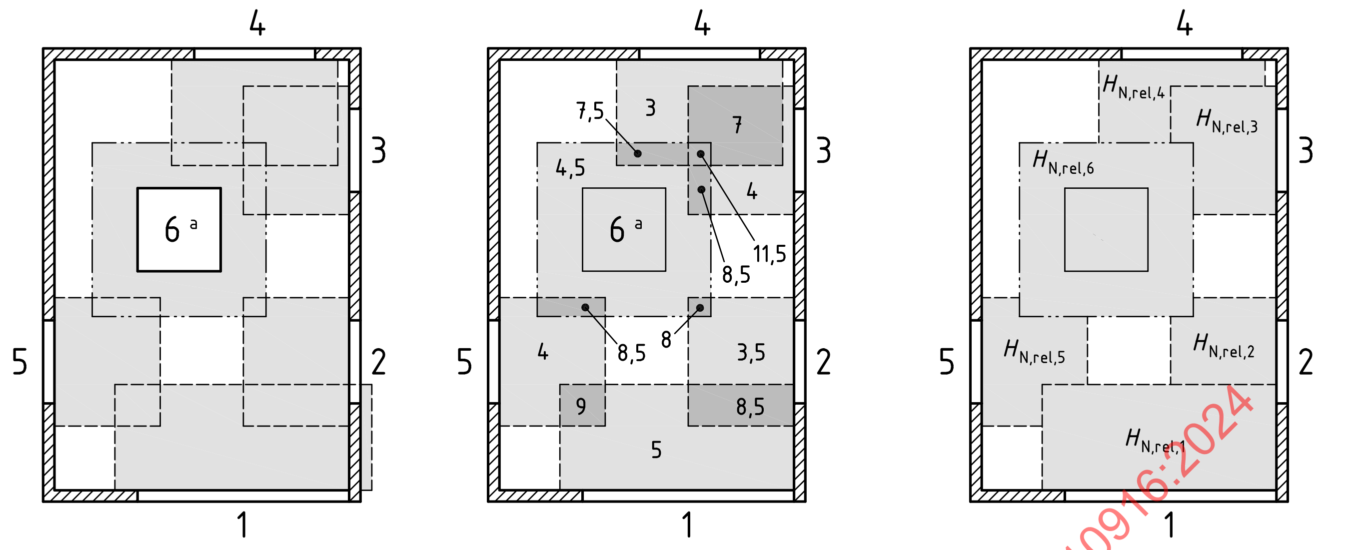
Figure A.3 — Impact of facade opening on daylight area for vertical facades



Key

(light grey)	A_D
(dark grey)	A_{ND}

Figure A.4 — Impact of roof opening on daylight area for rooflights



a) Daylight areas of the different vertical facades (1 – 5) and the rooflight (6)

b) Approach 1: Superposition of daylight factors in the overlapping daylight areas

c) Approach 2: The more favourable lighting condition is taken for the respective daylight area: $F_{D,S,1} > F_{D,S,6} > F_{D,S,5} = F_{D,S,3} > F_{D,S,2} > F_{D,S,4}$

Key

(light grey)	A_D
(dark grey)	A_{ND}
a	Rooflight.

Figure A.5 — Superposition and penetration of daylight areas for vertical facades and rooflights

A.3 Daylight supply factor for vertical facades

A.3.1 Daylight factor classification

The daylight factor for vertical facades can be obtained by several means, e.g. graphical, analytical, or computer-based approaches. Here, a simplified analytical approach allowing to account for the major parameters classifying the daylight availability in vertical lit rooms is provided.

The amount of daylight available in an area j being evaluated depends on the transparency index $I_{Tr,j}$, the space depth index $I_{RD,j}$, and the shading index $I_{Sh,j}$. These index values are determined as follows.

— Transparency index $I_{Tr,j}$

Formula (A.4) is used to calculate the transparency index.

$$I_{Tr,j} = \frac{A_{Ca}}{A_D} \tag{A.4}$$

where

A_{Ca} is the area of the raw building carcass opening of the area under evaluation;

A_D is the partial area which is lit by daylight as calculated by Formula (A.1).

All areas below the work plane (e.g. 0,8 m above floor level in office spaces) are ignored. The height of the work plane is given for individual utilization profiles in DIN V 18599-10[3].

— Space depth index $I_{RD,j}$

Formula (A.5) is used to calculate the space depth index $I_{RD,j}$.

$$I_{RD,j} = \frac{a_D}{h_{Li} - h_{Ta}} \quad \text{(A.5)}$$

— Shading index $I_{Sh,j}$

The shading index $I_{Sh,j}$ accounts for all effects which restrict the amount of daylight striking the facade. This includes shading by parts of the building itself, such as those that occur due to horizontal and vertical projections, light wells, courtyards, and atrium arrangements. It also takes into consideration any reduction of incident light by the glazed double facades (GDF — also glazed curtain walls). The shading index $I_{Sh,j}$ is calculated using Formula (A.6).

$$I_{Sh,j} = I_{Sh,lsh} I_{Sh,hf} I_{Sh,vf} I_{Sh,In,At} I_{Sh,GDF} \quad \text{(A.6)}$$

where

$I_{Sh,j}$	is the shading index of the area j under evaluation;
$I_{Sh,lsh}$	is the correction factor for linear shading of the area under evaluation as calculated using Formula (A.7);
$I_{Sh,hA}$	is the correction factor for an overhang shading of the area being evaluated, calculated using Formula (A.8);
$I_{Sh,vA}$	is the correction factor for a side shading of the area under evaluation as calculated using Formula (A.9);
$I_{Sh,In,At}$	is the correction factor for internal courtyard and atrium shading of the area under evaluation as calculated using Formula (A.11);
$I_{Sh,GDF}$	is the correction factor for glazed double facades of the area being evaluated, calculated using Formula (A.12).

NOTE A reduction by thick walls in relation to the carcass opening can be approximately described using the factors $I_{Sh,hA}$ and $I_{Sh,vA}$.

To facilitate the calculations, a window located at the centre of the facade area being evaluated can be used as the reference point for which the shading is calculated. If different forms and degrees of shading affect the area being evaluated, the mean value of the respective factors shall be calculated.

$I_{Sh,lsh}$, $I_{Sh,hf}$, $I_{Sh,vf}$, $I_{Sh,In,At}$ and $I_{Sh,GDF}$ can be determined using the following methods:

— Linear shading, correction factor $I_{Sh,lsh}$

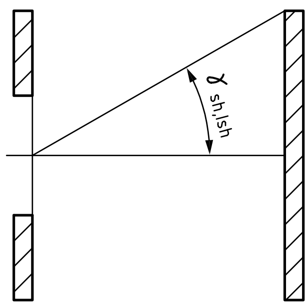


Figure A.6 — Cross-section diagram to illustrate the effect of the linear shading altitude angle $\gamma_{Sh,lsh}$

The linear shading altitude angle $\gamma_{Sh,lsh}$ is measured from the centre of the facade section being evaluated for lighting aspects (on the plane of the external wall surface) as shown in Figure A.6. Formula (A.7) is used to calculate the correction factor which accounts for linear shading.

$$I_{Sh,lsh} = \cos(1{,}5 \times \gamma_{Sh,lsh}) \quad \text{for } \gamma_{Sh,lsh} < 60°$$

$$I_{Sh,lsh} = 0 \quad \text{for } \gamma_{Sh,lsh} \geq 60° \qquad \text{(A.7)}$$

where $\gamma_{Sh,lsh}$ is the shading altitude angle as shown in Figure A.6.

— Horizontal projections, correction factor $I_{Sh,hf}$

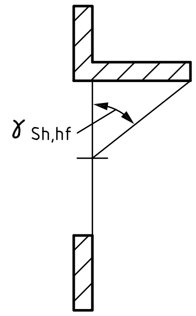


Figure A.7 — Cross-section diagram to illustrate the effect of the horizontal shading angle $\gamma_{Sh,hf}$

The horizontal shading angle $\gamma_{Sh,hf}$ due to a horizontal projection is measured from the centre of the facade section being evaluated for lighting aspects (on the plane of the external wall surface) as shown in Figure A.7. Formula (A.8) is used to calculate the correction factor which accounts for shading by a horizontal projection.

$$I_{Sh,hf} = \cos(1{,}33 \cdot \gamma_{Sh,hf,j}) \quad \text{for } \gamma_{Sh,hf} < 67{,}5°$$

$$I_{Sh,hf} = 0 \quad \text{for } \gamma_{Sh,hf} \geq 67{,}5° \qquad \text{(A.8)}$$

where $\gamma_{Sh,hf}$ is the horizontal shading angle due to a horizontal projection as shown in Figure A.7.

— Vertical projections, correction factor $I_{Sh,vf}$

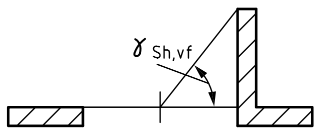


Figure A.8 — Cross-section ("top view") diagram to illustrate the effect of the vertical shading angle $\gamma_{Sh,vf}$

The vertical shading angle $\gamma_{Sh,vf}$ due to a vertical projection is measured from the centre of the facade section being evaluated for lighting aspects (on the plane of the external wall surface) as shown in Figure A.8. Formula (A.9) is used to calculate the correction factor which accounts for shading by a vertical projection.

$$I_{Sh,vf} = 1 - \frac{\gamma_{Sh,vf,j}}{300°} \qquad \text{(A.9)}$$

where $\gamma_{Sh,vf}$ is the vertical shading angle due to a vertical projection as shown in Figure A.8.

— Courtyards and atria (glazed forecourts), correction factor $I_{Sh,In,At}$

There are very many different design variants for courtyards and atria or glazed forecourts. The calculations are based on an internal courtyard surrounded on all four sides by the building. Better daylight availability can be expected if only three or two sides (linear courtyards) of the courtyard are bordered by the building. This can be calculated and proved using separate, detailed calculation methods.

The geometry of an internal courtyard is characterized by a geometrical index value, the so-called well index I_{well} :

$$I_{\mathrm{well}} = \frac{h_{\mathrm{In,At}} \left(a_{\mathrm{In,At}} + b_{\mathrm{In,At}} \right)}{2 \times a_{\mathrm{In,At}}\, b_{\mathrm{In,At}}} \qquad \text{(A.10)}$$

NOTE In daylight literature *wi* is used as symbol for the well index.

When determining the well index I_{well} for an area being evaluated, the height measured from the floor of the respective area is considered to be the height of the courtyard or atrium (Figure A.9).

where

$a_{\mathrm{In,At}}$	is the depth of the courtyard or atrium;
$b_{\mathrm{In,At}}$	is the width of the courtyard or atrium;
$h_{\mathrm{In,At}}$	is the height of the courtyard or atrium, measured from the floor of the storey being evaluated;
I_{well}	is the well index used to account for the geometry of the courtyard or atrium.

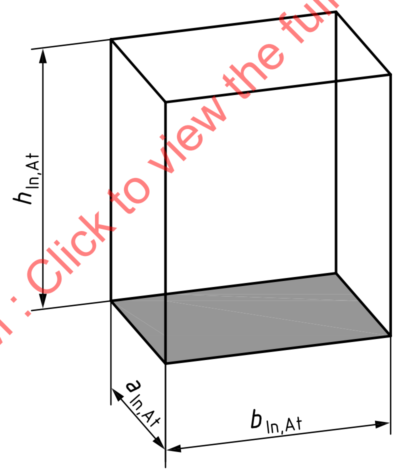


Figure A.9 — Illustration of the geometrical parameters used to define the well index I_{well}

The correction factor for taking into consideration building shading in internal courtyards, light wells, or atria is:

$I_{\mathrm{Sh,In,At}} = 1 - 0{,}85\, I_{\mathrm{well}}$ for internal courtyards

$I_{\mathrm{Sh,In,At}} = \tau_{\mathrm{Sh,In,At,D65}} k_{\mathrm{Sh,In,At,1}} k_{\mathrm{Sh,In,At,2}} k_{\mathrm{Sh,In,At,3}} \left(1 - 0{,}85\, I_{\mathrm{well}}\right)$ for atria (A.11)

$I_{\mathrm{Sh,In,At}} = 0$ for $I_{\mathrm{well}} > 1{,}18$

where

$\tau_{Sh,In,At,D65}$	is the transmittance of the atrium glazing for vertical light incidence;
$k_{Sh,In,At,1}$	is the framing factor for frames in the atrium facade;
$k_{Sh,In,At,2}$	is the dirt on glazing factor of the atrium glazing;
$k_{Sh,In,At,3}$	is the reduction factor for diffuse light incidence on the atrium glazing (usually, 0,85 is considered to be adequate).

— Glazed double facade (glazed curtain wall), correction factor $I_{Sh,GDF}$

The correction factor for glazed double facades or curtain walls bounding on the space being evaluated is directly deduced from the parameters of the additional glazing layer:

$$I_{Sh,GDF} = \tau_{Sh,GDF,D65} k_{Sh,GDF,1} k_{Sh,GDF,2} k_{Sh,GDF,3} \quad \text{(A.12)}$$

where

$\tau_{Sh,GDF,D65}$	is the transmittance of the external layer of glazing of the facade, for vertical light incidence;
$k_{Sh,GDF,1}$	is the reduction factor for frames in the double-glazed facade;
$k_{Sh,GDF,2}$	is the reduction factor for pollution of the glazing of the double-glazed facade;
$k_{Sh,GDF,3}$	is the reduction factor for non-vertical light incidence on the facade glazing (usually, 0,85 is considered to be adequate).

The effects of vertical and horizontal subdivisions in the space between the two facade layers can be approximated by treating these as vertical and horizontal projections with the index values $I_{Sh,vA}$ and $I_{Sh,hA}$. In glazed double facades, it is assumed that pollution of the space between the outer glazing and the space wall is negligible, so that it is usually adequate to take only the dirt deposited on the actual facade surface into consideration [also refer to Formula (A.21)]. In this case, $k_{Sh,GDF,2}$ = 1. The correction factor for frames and subdivisions is calculated as follows:

$$k_{Sh,GDF,1,j} = 1 - \frac{\text{area of structural components}}{\text{area of raw building carcass opening}} = \frac{\text{transparent area}}{\text{area of raw building carcass opening}} \quad \text{(A.13)}$$

Only that part of the external facade glazing which is projected onto the transparent portions of the inner facade is taken into consideration when calculating the factor $k_{Sh,GDF,1}$.

— Daylight factor of the raw building carcass opening

The index values $I_{Tr,j}$, $I_{RD,j}$, and $I_{Sh,j}$ can be used to calculate an approximate value for the daylight factor of the area being evaluated on the basis of the raw opening dimensions:

$$D_{Ca,j} = \left(4{,}13 + 20{,}0 \times I_{Tr,j} - 1{,}36 \times I_{RD,j}\right) I_{Sh,j} \text{ in } \% \quad \text{(A.14)}$$

For combinations of a larger space depth index value $I_{RD,j}$ and low transparency index values $I_{Tr,j}$, Formula (A.14) can produce negative $D_{Ca,j}$ values. In such cases, $D_{Ca,j}$ shall be assumed to be zero or shall be calculated by a more detailed method. For simple estimates, daylight availability can be grouped into four classes as shown in Table A.1.

Table A.1 — Daylight availability classification as a function of the daylight factor $D_{Ca,j}$ of the raw building carcass opening

Daylight factor $D_{Ca,j}$	Classification of daylight availability
$D_{Ca,j} \geq 6$ %	Strong
6 % > $D_{Ca,j} \geq 4$ %	Medium
4 % > $D_{Ca,j} \geq 2$ %	Low
$D_{Ca,j} < 2$ %	None

If a daylight factor which has been calculated using another validated method is known, then this can be used instead of the value calculated by Formula (A.14) when classifying the daylight availability according to Table A.1. In this case, the daylight factor shall have been determined on the basis of the mean value of the daylight measured on the axis running parallel to the respective facade section and at a distance of half the space depth from the facade.

A.3.2 Daylight supply factor

A.3.2.1 General

The following section first explains how the facade characteristics are to be described and then how the daylight availability is determined on the basis of the correlation of the daylight availability (daylight factor) of the building area as defined in A.3.1 with the facade characteristics. The light passing through facade systems and the associated illumination of the adjacent space depends on the spatial and temporal distribution of the external illuminance conditions in relation to the facade element and the spatial distribution of the light by the facade system (i.e. its optical and control-technological characteristics). From the lighting-engineering aspect, two facade states shall be distinguished for facades with variable solar light shading systems and/or glare-protection systems:

— solar and/or glare protection system not activated, i.e. the sun is not shining on the facade;

— solar and/or glare protection system is activated, i.e. the sun is shining on the facade.

The daylight supply factor $F_{D,s,j}$ shall be determined using Formula (A.15) to achieve temporal weighting of the orientation-dependent occurrence of two different facade states, i.e. either with activated solar and/or glare protection or with de-activated solar and/or glare protection. The protection against solar radiation and/or glare is activated as soon as direct sunlight shines on the facade.

Formula (A.15) is used to calculate the daylight supply factor $F_{D,s,j}$.

$$F_{D,s,j} = t_{rel,D,SNA,j}\, F_{D,s,SNA,j} + t_{rel,D,SA,j}\, F_{D,s,SA,j} \quad (A.15)$$

where

$t_{rel,D,SNA,j}$ is the relative portion of the total operating time during which the solar and/or glare protection system is not activated as given in Table A.3. It is a function of the latitude γ of the considered site, H_{dir}/H_{glob} representing the climate and facade orientation;

$t_{rel,D,SA,j}$ is the relative portion of the total operating time during which the solar and/or glare protection system is activated. $t_{rel,D,SA}$ can be obtained by $t_{rel,D,SA} = 1 - t_{rel,D,SNA}$;

$F_{D,s,SNA,j}$ is the daylight supply factor of the area j being evaluated at times when the solar and/or glare protection system is not activated, as given in Table A.7. It is a function of the latitude γ of the considered site, H_{dir}/H_{glob} representing the climate, the facade orientation, daylight availability (daylight factor), and the maintained illuminance;

$F_{D,s,SA,j}$ is the daylight supply factor of the area j being evaluated at times when the solar and/or glare protection system is activated, as given in Table A.8.

A set of ratios H_{dir}/H_{glob} for representative locations worldwide is given in A.3.2.1.

A.3.2.2 Luminous exposure ratios at different sites (climates and latitudes)

Figure A.10 shows the segmentation of locations worldwide according to 15° latitude corridors. For each of the latitude corridors, Table A.2 contains a representative cloudy and sunny location with the ratio H_{dir}/H_{glob}. For other specific locations of interest, the ratio H_{dir}/H_{glob} can be obtained by evaluation of the corresponding weather data sets (e.g. TRY – weather data sets). The direct and global horizontal illuminances are summed up daily from 8:00 h to 17:00 h over the whole year.

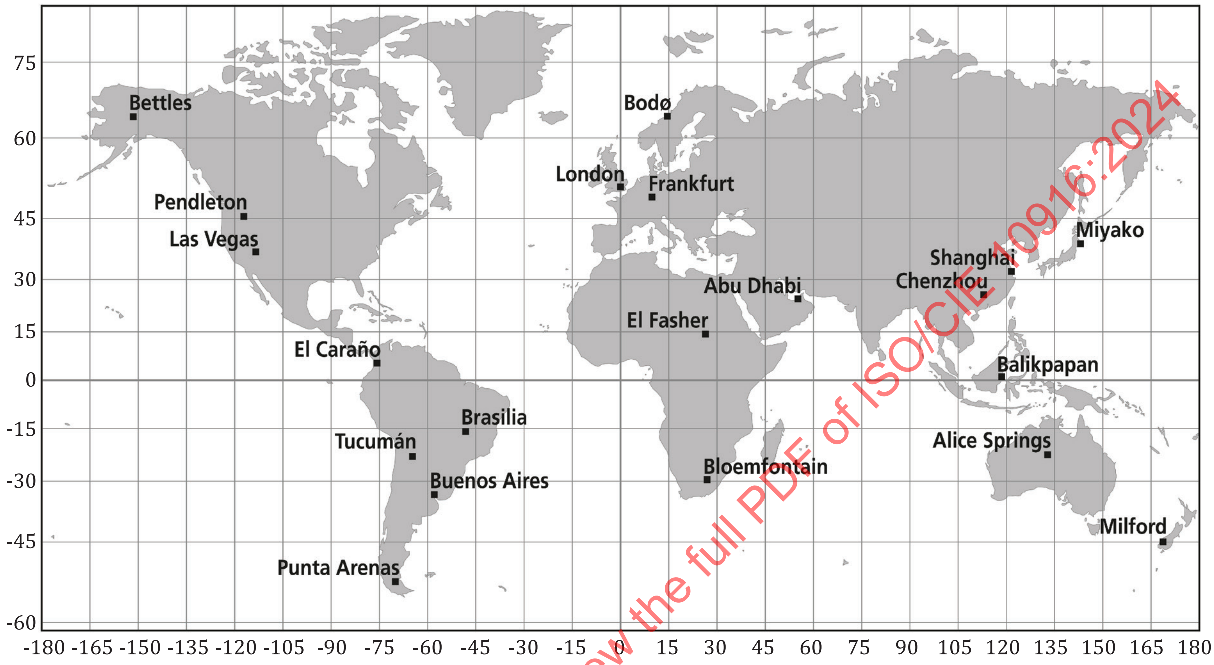


Figure A.10 — Selected sites for which ratios H_{dir}/H_{glob} are provided with assignment of latitude

Table A.2 — Representative locations on the northern and southern hemispheres with the corresponding luminous exposure ratios H_{dir}/H_{glob}

Geographical location				Climate	Representative site	Luminous exposure ratio H_{dir}/H_{glob} [–]
Corridor		Latitude γ	Longitude γ			
Northern hemisphere	60° to 75°	67,3°	14,4°	Cloudy	Bodø, N	0,40
		66,9°	−151,5°	Sunny	Bettles, USA	0,49
	45° to 60°	51,2°	−0,2°	Cloudy	London, GB	0,39
		50,0°	8,7°	Cloudy	Frankfurt, D	0,42
		45,7°	−118,9°	Sunny	Pendleton, USA	0,58
	30° to 45°	31,2°	121,4°	Cloudy	Shanghai, VRC	0,36
		39,7°	145,0°	Cloudy	Miyako, J	0,45
		36,1°	−115,2°	Sunny	Las Vegas, USA	0,71
	15° to 30°	25,8°	113,0°	Cloudy	Chenzhou, VRC	0,34
		24,4°	54,5°	Sunny	Abu Dhabi, AE	0,58
	0° to 15°	5,7°	−76,6°	Cloudy	El Caraño, CO	0,34
		13,6°	25,3°	Sunny	El Fasher, SUD	0,66

Table A.2 *(continued)*

Geographical location		Latitude γ	Longitude γ	Climate	Representative site	Luminous exposure ratio H_{dir}/H_{glob} [–]
Corridor						
Southern hemisphere	0° to 15°	−1,3°	116,9°	Cloudy	Balikpapan, RI	0,38
		−15,8°	−47,9°	Sunny	Brasilia, BR	0,53
	15° to 30°	−26,8°	−65,2°	Cloudy	Tucumán, RA	0,54
		−23,8°	133,9°	Sunny	Alice Springs, AUS	0,67
	30° to 45°	−34,8°	−58,5°	Cloudy	Buenos Aires, AR	0,55
		−30,0°	26,3°	Sunny	Bloemfontein, RSA	0,68
	45° to 60°	−53,0°	−70,9°	Cloudy	Punta Arenas, RCH	0,39
		−44,7°	167,9°	Sunny	Milford Sound, NZ	0,50

A.3.2.3 Relative times, shading activated, shading not activated for vertical facades

Table A.3, Table A.4 and Table A.5 hold the relative times $t_{rel,D,SNA,j}$ as a function of the latitude γ of the considered site, H_{dir}/H_{glob} representing the climate and facade orientation.

The relative times $t_{rel,D,SNA,j}$ are provided for unobstructed facades. For shading indices $I_{Sh,j}$ of obstructed facades of less than 0,5, especially for higher latitudes $\gamma \geq 45°$, it is recommended to set $t_{rel,D,SNA} = 1$. This nevertheless shall not give reason to assume that glare protection for the facade is unnecessary. Such protection can be necessary due to individual types of usage.

If the shading index $I_{Sh,j}$ of a shaded facade is less than 0,5, then the relative times $t_{rel,D,SNA,j}$ and $t_{rel,D,SA,j}$ for a north-facing facade should be used. Depending on the operating times of the area being evaluated, even north-facing facades can receive direct sunlight for limited periods. However, for simplified calculations, $t_{rel,D,SNA,j}$ is assumed to be 0, but this shall not give reason to assume that glare protection for north-facing facades is unnecessary. Such protection can be necessary due to individual types of usage[2].

$t_{rel,D,SNA}$ has been calculated for office conditions but can be used for other user profiles generally with sufficient accuracy as well.

Table A.3 — Relative times $t_{rel,D,SNA,j}$ for not activated solar radiation and/or glare protection systems, as a function of the facade orientation (south), the geographic latitude γ, and the ratio H_{dir}/H_{glob}

H_{dir}/H_{glob}	t_{SNA} South[a] γ 0°	10°	20°	30°	40°	50°	60°	70°	80°
0,0	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
0,1	0,99	0,97	0,94	0,93	0,96	0,98	0,98	0,93	0,88
0,2	0,94	0,91	0,86	0,84	0,86	0,87	0,86	0,80	0,72
0,3	0,89	0,86	0,79	0,75	0,75	0,76	0,75	0,69	0,61
0,4	0,83	0,80	0,71	0,65	0,64	0,65	0,65	0,60	0,53
0,5	0,71	0,67	0,57	0,50	0,49	0,50	0,51	0,47	0,40
0,6	0,55	0,51	0,41	0,33	0,32	0,34	0,36	0,32	0,23
0,7	0,47	0,43	0,32	0,24	0,23	0,26	—	—	—
0,8	—	0,42	0,32	0,24	0,23	0,26	—	—	—
0,9	—	0,42	0,32	0,24	0,23	0,26	—	—	—

[a] Corresponds to a north facade in the southern hemisphere.

Table A.4 — Relative times $t_{rel,D,SNA,j}$ for not activated solar radiation and/or glare protection systems, as a function of the facade orientation (east/west), the geographic latitude γ, and the ratio H_{dir}/H_{glob}

t_{SNA} East/West									
H_{dir}/H_{glob}	γ								
	0°	**10°**	**20°**	**30°**	**40°**	**50°**	**60°**	**70°**	**80°**
0,0	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
0,1	0,99	0,98	0,97	0,97	1,00	1,00	0,99	0,95	0,92
0,2	0,95	0,94	0,92	0,92	0,94	0,94	0,93	0,88	0,85
0,3	0,91	0,89	0,87	0,86	0,88	0,88	0,87	0,83	0,79
0,4	0,84	0,83	0,80	0,79	0,81	0,82	0,82	0,80	0,78
0,5	0,74	0,73	0,70	0,70	0,73	0,76	0,77	0,77	0,76
0,6	0,64	0,63	0,61	0,61	0,65	0,69	0,72	0,72	0,73
0,7	0,59	0,58	0,56	0,56	0,61	0,65	—	—	—
0,8	—	0,58	0,56	0,56	0,61	0,65	—	—	—
0,9	—	0,58	0,56	0,56	0,61	0,65	—	—	—

Table A.5 — Relative times $t_{rel,D,SNA,j}$ for not activated solar radiation and/or glare protection systems, as a function of the facade orientation (north/south), the geographic latitude γ, and the ratio H_{dir}/H_{glob}

t_{SNA} North[a]									
H_{dir}/H_{glob}	γ								
	0°	**10°**	**20°**	**30°**	**40°**	**50°**	**60°**	**70°**	**80°**
0,0	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
0,1	0,99	0,99	0,99	1,00	1,00	1,00	1,00	1,00	1,00
0,2	0,97	0,97	0,98	1,00	1,00	1,00	1,00	1,00	1,00
0,3	0,92	0,92	0,94	0,98	1,00	1,00	1,00	1,00	1,00
0,4	0,84	0,85	0,89	0,94	1,00	1,00	1,00	1,00	1,00
0,5	0,77	0,79	0,83	0,91	0,98	1,00	1,00	1,00	1,00
0,6	0,73	0,75	0,80	0,89	0,98	1,00	1,00	1,00	1,00
0,7	0,71	0,73	0,79	0,88	0,98	1,00	—	—	—
0,8	—	0,73	0,79	0,88	0,98	1,00	—	—	—
0,9	—	0,73	0,79	0,88	0,98	1,00	—	—	—

[a] Corresponds to a south facade in the southern hemisphere.

A.3.2.4 Determination of daylight supply factor for sunshading not activated $F_{D,s,SNA,j}$

Formula (A.16) is used to calculate an approximate value of the effective transmittance for periods during which the solar and/or glare protection system is not activated:

$$\tau_{eff,SNA,j} = \tau_{D65,SNA} k_1 k_2 k_3 \tag{A.16}$$

where

$\tau_{D65,SNA}$ is the transmittance of the facade glazing for vertical light incidence;

k_1 is the reduction factor for frames and structural divisions, as calculated using Formula (A.13);

k_2 is the reduction factor for pollution of the glazing;

k_3 is the reduction factor for non-vertical light incidence on the facade glazing (usually, 0,85 is considered to be adequate).

If the transparent or translucent facade element to be evaluated comprises different components, the effective transmittance shall be weighted according to the relative proportion of the areas of the respective components. When determining the shading index by applying Formulae (A.6) and (A.12), the effect of the outer glazing of glazed double facades shall be calculated separately. Table A.6 shows typical values of the transmittance $\tau_{D65,SNA}$ for visible light. If the reduction factor k_1 for frames and structural divisions is not known, it should be assumed to be 0,7.

Table A.6 — Typical values of the transmittance $\tau_{D65,SNA}$ of transparent and translucent building components

Type	Thermal transmittance of glazing unit U (W·m^{-2}·K)	Total solar energy transmittance of glazing unit $g_{\perp}$	$\tau_{D65,SNA}$
Single glazing	5,8	0,87	0,90
Double glazing	2,9	0,78	0,82
Triple glazing	2,0	0,70	0,75
low-e glazing, double glazed	1,7	0,72	0,74
low-e glazing, double glazed	1,4	0,67	0,78
low-e glazing, double glazed	1,2	0,65	0,78
low-e glazing, triple glazed	0,8	0,50	0,69
low-e glazing, triple glazed	0,6	0,50	0,69
Solar protection glazing, double	1,3	0,48	0,59
Solar protection glazing, double	1,2	0,37	0,67
Solar protection glazing, double	1,2	0,25	0,40

The daylight supply factor $F_{D,s,SNA,j}$ is a function of the daylight availability, the maintained illuminance $\bar{E}_m$, the effective transmittance of the facade $\tau_{eff,SNA,j}$ with deactivated solar and/or glare protection system and of the facade orientation. Estimated values can be taken from Table A.7.

The daylight supply factor $F_{D,s,SNA}$ can be obtained from Table A.7, Table A.8, and Table A.9 as a function of:

— the daylight factor D;

— the geographic location, i.e. latitude γ;

— the climate, characterized by the ratio H_{dir}/H_{glob};

— the maintained illuminance $\bar{E}_m$; and

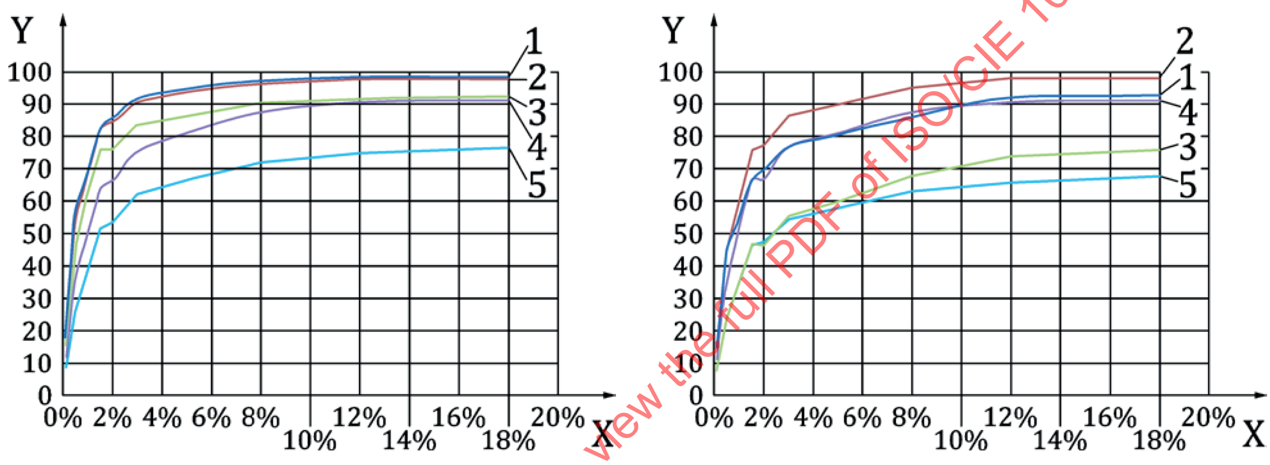
— the facade orientation.

For maintained illuminances $\bar{E}_m$ of less than 100 lx, the $F_{D,s,SNA,j}$ values for $\bar{E}_m$ = 100 lx should be used. Correspondingly, for maintained illuminances $\bar{E}_m$ of more than 1 000 lx, the $F_{D,s,SNA,j}$ values for $\bar{E}_m$ = 1 000 lx should be used and not extrapolated. For other $\bar{E}_m$ more than 100 lx and less than 1 000 lx, values can be linearly interpolated between the listed next closest $\bar{E}_m$. Values for D can linearly be interpolated with the listed next closest D between D = 0 % and D = 18 %. For D more than 18 % the $F_{D,s,SNA,j}$ values for D = 18 % should be used. For D = 0 %, the value of $F_{D,s,SNA,j}$ is 0.

The relevant D for interpolation in Table A.7, Table A.8, and Table A.9 is obtained from:

$$D = \tau_{eff} \times D_{Ca} \qquad \text{(A.17)}$$

Figure A.11 provides an exemplarily parametrization for climates with mainly cloudy sky conditions for different locations.



Key

X-axis daylight factor (%)

Y-axis daylight factor, $F_{D,s,SNA,j}$ (%)

1 0° to 15°

2 15° to 30°

3 30° to 45°

4 45° to 60°

5 60° to 75°

Figure A.11 — Example of a set of functions used to determine the daylight supply factor $F_{D,s,SNA,j}$ and $F_{D,s,SA,j}$ as a function of D and γ according to Table A.7 for $\bar{E}_m$ = 500 lx and a south-facing facade

Table A.7 — Daylight supply factor $F_{D,s,SNA,j}$ for sun shading not activated parameterized by D, γ, $\bar{E}_m$, climate (H_{dir}/H_{glob}), facade orientation, and geographic location for orientation South

$F_{D,s,SNA,j}$ %												
South facade[a]												
Geographic location γ	$\bar{E}_m$ lx	H_{dir}/H_{glob}	D %									
			0,125	0,5	1,0	1,5	2,0	3,0	5,0	8,0	12,0	18,0
0° to 15°	100	0,34	31,9	95,6	97,9	99,4	99,7	99,9	99,9	100,0	100,0	100,0
		0,66	28,1	84,3	94,0	98,2	98,1	99,3	99,3	100,0	100,0	100,0
	300	0,34	25,1	75,2	83,3	91,9	94,0	96,8	98,0	99,2	99,6	99,6
		0,66	19,9	59,8	67,7	78,3	82,5	88,4	90,5	95,5	98,2	98,3
	500	0,34	18,5	55,6	68,2	82,2	85,7	91,6	94,8	97,2	98,5	98,5
		0,66	14,7	44,0	54,3	65,7	69,3	76,4	80,1	85,6	91,5	92,0
	750	0,34	12,9	38,6	52,6	70,2	75,0	84,4	90,0	94,4	96,6	96,8
		0,66	10,3	30,9	42,4	55,4	58,8	66,6	70,6	76,2	83,1	84,2
	1 000	0,34	9,7	29,1	41,0	59,2	64,7	77,2	85,0	91,4	94,6	94,9
		0,66	7,8	23,3	33,4	47,2	50,7	59,7	64,2	70,0	76,3	77,9
15° to 30°	100	0,34	30,9	92,8	95,8	97,7	97,7	98,6	98,9	99,3	99,6	99,7
		0,58	29,4	88,1	96,6	99,2	98,6	99,6	99,6	100,0	100,0	100,0
	300	0,34	24,6	74,0	83,7	91,4	92,3	95,4	96,8	98,2	98,6	99,0
		0,58	20,6	61,7	76,8	87,8	88,4	94,3	95,9	98,5	99,5	99,5
	500	0,34	18,2	54,6	69,7	83,4	85,5	91,2	94,2	96,8	97,7	98,2
		0,58	14,8	44,3	61,0	75,4	77,0	85,9	89,8	94,6	97,2	97,3
	750	0,34	12,5	37,5	54,1	72,2	76,0	85,2	90,3	94,7	96,4	97,5
		0,58	10,3	30,8	46,9	62,7	65,0	76,3	81,9	89,2	93,6	94,0
	1 000	0,34	9,3	28,1	42,1	61,2	66,0	78,8	86,0	92,2	94,9	95,6
		0,58	7,7	23,2	37,0	52,6	55,4	67,9	74,9	83,8	89,7	90,4
30° to 45°	100	0,36	30,8	92,4	95,9	97,8	97,8	98,7	99	99,4	99,6	99,6
		0,71	17,8	53,3	70,1	80,0	78,4	84,6	85,6	89,5	90,3	90,9
	300	0,36	24,3	73	83,1	91,1	92	95,3	96,7	98,2	98,7	98,8
		0,71	10,8	32,3	46,6	57,1	56,8	66,4	70,0	77,0	82,4	83,6
	500	0,36	17,9	53,7	69	82,7	84,8	90,8	93,8	96,6	97,7	97,8
		0,71	7,6	22,8	36,4	46,6	46,2	55,3	59,5	67,8	73,6	75,4
	750	0,36	12,3	36,9	53,5	71,4	75,1	84,5	89,6	94,2	96,2	96,4
		0,71	5,3	16,0	27,8	38,2	38,2	47,1	51,3	59,6	65,9	68,2
	1 000	0,36	9,2	27,7	41,7	60,5	65,1	77,9	85,1	91,5	94,5	94,9
		0,71	4,1	12,4	21,9	32,0	32,5	41,5	46,0	54,2	60,3	63,0

[a] Corresponds to a north facade in the southern hemisphere.

Table A.7 *(continued)*

$F_{D,s,SNA,j}$ %												
South facade[a]												
Geographic location γ	$\bar{E}_m$ lx	H_{dir}/H_{glob}	D %									
			0,125	**0,5**	**1,0**	**1,5**	**2,0**	**3,0**	**5,0**	**8,0**	**12,0**	**18,0**
45° to 60°	100	0,39	25,3	75,8	83,2	88,4	88,5	90,9	92,0	93,4	94,1	94,5
		0,58	24,3	72,8	84,2	90,0	88,2	91,8	92,0	94,1	94,4	94,8
	300	0,39	17,2	51,7	64,0	75,3	76,7	83,7	87,5	91,4	93,1	93,5
		0,58	16,7	50,2	66,5	78,0	77,5	85,0	87,7	92,3	94,0	94,4
	500	0,39	12,0	36,0	49,8	63,7	66,4	75,3	81,1	87,6	90,7	91,3
		0,58	11,5	34,6	51,3	66,0	66,6	76,4	80,7	87,1	90,1	90,8
	750	0,39	8,1	24,3	36,9	51,7	54,5	65,6	73,0	81,6	86,2	87,1
		0,58	8,0	23,9	38,9	54,5	56,0	68,3	74,8	83,0	87,0	87,9
	1 000	0,39	6,1	18,3	28,4	42,4	45,4	57,9	66,5	76,3	82,2	83,3
		0,58	6,0	17,9	30,2	45,1	46,9	60,4	68,5	78,6	83,4	84,5
60° to 75°	100	0,40	20,6	61,7	68,3	72,9	73,0	75,7	76,9	78,3	78,9	80,3
		0,48	17,8	53,4	60,0	64,2	64,2	66,8	68,1	69,7	70,5	72,5
	300	0,40	13,2	39,7	51,3	61,5	62,5	68,3	71,5	75,3	77,1	78,7
		0,48	11,9	35,7	46,1	54,4	54,6	59,9	62,6	66,3	68,0	70,2
	500	0,40	8,6	25,7	38,1	51,4	53,6	61,9	66,7	72,1	74,9	76,5
		0,48	7,9	23,8	35,6	46,3	47,2	54,1	57,9	62,9	65,4	67,6
	750	0,40	5,7	17,1	26,7	39,8	42,6	53,5	60,1	67,3	70,9	72,6
		0,48	5,4	16,1	25,7	37,5	39,3	47,8	52,7	58,9	62,2	64,5
	1 000	0,40	4,3	12,8	20,1	31,4	33,8	46,0	54,3	63,1	67,7	69,5
		0,48	4,0	12,1	19,5	30,1	32,1	42,2	48,2	55,4	59,4	61,8

[a] Corresponds to a north facade in the southern hemisphere.

Table A.8 — Daylight supply factor $F_{D,s,SNA,j}$ for sun shading not activated parameterized by D, γ, $\bar{E}_m$, climate (H_{dir}/H_{glob}), facade orientation, and geographic location for orientations East/West

$F_{D,s,SNA,j}$ %												
East/West facade												
Geographic location γ	$\bar{E}_m$ lx	H_{dir}/H_{glob}	D %									
			0,125	**0,5**	**1,0**	**1,5**	**2,0**	**3,0**	**5,0**	**8,0**	**12,0**	**18,0**
0° to 15°	100	0,34	31,7	95,1	97,4	98,9	99,2	99,4	99,4	99,5	99,5	99,5
		0,66	26,6	79,9	89,1	93,1	92,9	94,1	94,2	94,8	94,8	94,8
	300	0,34	24,6	73,9	81,8	90,2	92,3	95,0	96,2	97,3	97,8	97,9
		0,66	15,1	45,2	51,1	59,2	62,3	66,8	68,4	72,1	74,2	75,9
	500	0,34	18,0	53,9	66,1	79,7	83,1	88,9	91,9	94,2	95,5	95,8
		0,66	11,7	35,2	43,5	52,6	55,5	61,1	64,1	68,5	73,2	75,0
	750	0,34	12,5	37,5	51,0	68,1	72,7	81,8	87,3	91,5	93,6	94,0
		0,66	6,1	18,4	25,3	33,1	35,1	39,7	42,1	45,4	49,5	53,0
	1 000	0,34	9,4	28,1	39,7	57,3	62,5	74,6	82,2	88,4	91,5	92,0
		0,66	4,5	13,4	19,2	27,1	29,2	34,3	36,9	40,3	43,9	47,7
15° to 30°	100	0,34	30,8	92,3	95,3	97,2	97,2	98,1	98,4	98,7	99,0	99,1
		0,58	28,9	86,6	95,0	97,5	96,9	97,9	97,9	98,3	98,3	98,4
	300	0,34	23,9	71,9	81,4	88,9	89,7	92,8	94,2	95,5	96,0	96,3
		0,58	17,7	53,1	66,2	75,6	76,2	81,2	82,6	84,8	85,7	86,6
	500	0,34	17,2	51,7	66,1	79,0	81,1	86,5	89,4	91,8	92,7	93,2
		0,58	12,4	37,2	51,2	63,4	64,7	72,2	75,4	79,4	81,6	82,8
	750	0,34	11,8	35,2	50,8	67,9	71,6	80,3	85,0	89,2	91,0	92,0
		0,58	7,4	22,1	33,7	45,0	46,7	54,8	58,8	64,0	67,2	69,4
	1 000	0,34	8,7	26,2	39,2	56,8	61,4	73,2	80,0	85,8	88,4	89,3
		0,58	5,3	15,8	25,2	35,9	37,7	46,3	51,0	57,1	61,1	63,8
30° to 45°	100	0,36	30,6	91,8	95,3	97,2	97,2	98,1	98,4	98,7	98,9	99,0
		0,71	16,4	49,3	64,9	74,1	72,6	78,4	79,2	82,8	83,6	84,7
	300	0,36	23,4	70,3	80,1	87,8	88,6	91,8	93,2	94,6	95,1	95,4
		0,71	7,0	21,1	30,4	37,2	37,0	43,3	45,6	50,2	53,7	56,9
	500	0,36	16,8	50,5	64,9	77,7	79,7	85,3	88,2	90,8	91,8	92,3
		0,71	5,8	17,3	27,6	35,4	35,1	42,0	45,2	51,5	55,9	58,9
	750	0,36	11,4	34,1	49,4	66	69,5	78,2	82,8	87,1	89	89,7
		0,71	2,2	6,7	11,6	15,9	15,9	19,6	21,4	24,8	27,5	32,4
	1 000	0,36	8,4	25,3	38	55,1	59,4	71	77,6	83,4	86,1	87,1
		0,71	1,5	4,6	8,1	11,9	12,1	15,4	17,1	20,2	22,4	27,7

Table A.8 *(continued)*

$F_{D,s,SNA,j}$ %												
East/West facade												
Geographic location γ	$\bar{E}_m$ lx	H_{dir}/H_{glob}	D %									
			0,125	**0,5**	**1,0**	**1,5**	**2,0**	**3,0**	**5,0**	**8,0**	**12,0**	**18,0**
45° to 60°	100	0,39	25,0	75,0	82,3	87,4	87,5	89,9	91,0	92,4	93,0	93,5
		0,58	23,9	71,6	82,8	88,5	86,8	90,3	90,5	92,5	92,9	93,3
	300	0,39	16,2	48,7	60,2	70,9	72,2	78,8	82,4	86,1	87,6	88,4
		0,58	14,8	44,5	58,9	69,2	68,7	75,4	77,8	81,8	83,3	84,5
	500	0,39	11,0	33,1	45,8	58,6	61,1	69,2	74,6	80,6	83,4	84,5
		0,58	9,8	29,4	43,6	56,1	56,6	65,0	68,6	74,1	76,6	78,2
	750	0,39	7,3	21,9	33,1	46,4	49,0	59,0	65,6	73,3	77,5	79,0
		0,58	6,4	19,2	31,4	43,9	45,1	55,0	60,2	66,8	70,1	72,1
	1 000	0,39	5,4	16,2	25,1	37,6	40,3	51,3	58,9	67,7	72,8	74,7
		0,58	4,7	14,1	23,7	35,4	36,9	47,5	53,8	61,8	65,6	67,9
60° to 75°	100	0,40	20,9	62,8	69,5	74,3	74,3	77,1	78,3	79,7	80,3	81,6
		0,48	16,8	50,3	56,5	60,5	60,5	62,9	64,2	65,7	66,4	68,7
	300	0,40	12,5	37,6	48,6	58,4	59,3	64,8	67,8	71,4	73,2	74,7
		0,48	9,9	29,7	38,4	45,3	45,5	49,8	52,1	55,2	56,6	59,3
	500	0,40	7,9	23,7	35,0	47,3	49,3	57,0	61,3	66,3	68,9	70,9
		0,48	7,1	21,4	32,0	41,7	42,5	48,7	52,1	56,6	58,8	61,6
	750	0,40	5,1	15,3	23,8	35,5	38,0	47,7	53,6	60,0	63,2	65,5
		0,48	4,2	12,5	20,0	29,1	30,5	37,1	40,9	45,7	48,3	51,5
	1 000	0,40	3,7	11,2	17,6	27,5	29,6	40,3	47,6	55,3	59,3	62,0
		0,48	3,1	9,3	15,0	23,2	24,7	32,4	37,1	42,6	45,7	49,3

Table A.9 — Daylight supply factor $F_{D,s,SNA,j}$ for sun shading not activated, parameterized by D, γ, $\bar{E}_m$, climate (H_{dir}/H_{glob}), facade orientation, and geographic location for orientation North

$F_{D,s,SNA,j}$ %												
North facade[a]												
Geographic location γ	$\bar{E}_m$ lx	H_{dir}/H_{glob}	D %									
			0,125	**0,5**	**1,0**	**1,5**	**2,0**	**3,0**	**5,0**	**8,0**	**12,0**	**18,0**
0° to 15°	100	0,34	31,8	95,4	97,7	99,3	99,5	99,7	99,7	99,8	99,8	99,8
		0,66	27,2	81,6	91,0	95,1	94,9	96,1	96,2	96,8	96,8	96,8
	300	0,34	24,5	73,5	81,4	89,7	91,8	94,6	95,8	96,9	97,3	97,5
		0,66	14,5	43,5	49,2	56,9	59,9	64,2	65,8	69,4	71,4	73,3
	500	0,34	17,8	53,4	65,4	78,9	82,2	88,0	91,0	93,3	94,5	94,9
		0,66	10,6	31,7	39,1	47,3	49,9	55,0	57,6	61,7	65,8	68,2
	750	0,34	12,2	36,5	49,7	66,4	70,9	79,8	85,1	89,2	91,3	91,8
		0,66	5,3	15,9	21,9	28,6	30,3	34,3	36,4	39,3	42,8	46,7
	1 000	0,34	9,2	27,5	38,8	56,0	61,1	72,9	80,3	86,3	89,4	90,1
		0,66	4,0	12,0	17,2	24,3	26,2	30,8	33,1	36,1	39,3	43,5
15° to 30°	100	0,34	30,5	91,6	94,7	96,5	96,6	97,4	97,8	98,1	98,3	98,4
		0,58	28,8	86,4	94,8	97,3	96,7	97,7	97,7	98,1	98,1	98,2
	300	0,34	23,3	70,0	79,3	86,6	87,4	90,4	91,8	93,0	93,5	93,7
		0,58	16,8	50,5	62,9	71,9	72,5	77,2	78,6	80,7	81,5	82,7
	500	0,34	16,5	49,5	63,4	75,8	77,8	83,0	85,7	88,1	89,0	89,2
		0,58	11,5	34,6	47,6	58,8	60,1	67,0	70,0	73,8	75,8	77,4
	750	0,34	11,1	33,1	47,8	63,9	67,3	75,6	80,0	84,0	85,6	86,1
		0,58	6,7	20,0	30,5	40,7	42,3	49,6	53,2	58,0	60,8	63,5
	1 000	0,34	8,1	24,1	36,2	52,5	56,7	67,7	74,0	79,3	81,8	82,7
		0,58	4,7	14,0	22,3	31,7	33,4	40,9	45,1	50,5	54,1	57,2
30° to 45°	100	0,36	30,4	91,2	94,7	96,6	96,6	97,4	97,8	98,1	98,3	98,4
		0,71	16,6	49,9	65,6	74,9	73,4	79,2	80,1	83,7	84,5	85,5
	300	0,36	22,8	68,4	77,9	85,4	86,2	89,3	90,7	92	92,5	93,0
		0,71	6,9	20,7	29,8	36,5	36,3	42,5	44,8	49,3	52,7	55,9
	500	0,36	16,1	48,3	62,1	74,4	76,3	81,7	84,4	86,9	87,9	88,7
		0,71	5,8	17,3	27,6	35,4	35,1	42,0	45,2	51,5	55,9	58,9
	750	0,36	10,7	32	46,4	62	65,2	73,4	77,8	81,8	83,5	84,6
		0,71	2,0	6,1	10,5	14,5	14,4	17,8	19,4	22,5	24,9	30,0
	1 000	0,36	7,8	23,3	35	50,8	54,8	65,5	71,6	76,9	79,5	80,9
		0,71	1,4	4,1	7,2	10,5	10,7	13,6	15,1	17,8	19,8	25,3

[a] Corresponds to a south facade in the southern hemisphere.

Table A.9 *(continued)*

Geographic location γ	$\bar{E}_m$ lx	H_{dir}/H_{glob}	$F_{D,s,SNA,j}$ % — North facade[a] — D % 0,125	0,5	1,0	1,5	2,0	3,0	5,0	8,0	12,0	18,0
45° to 60°	100	0,39	24,7	74,2	81,4	86,4	86,5	88,9	89,9	91,3	92,0	92,5
		0,58	23,6	70,8	81,9	87,5	85,7	89,2	89,5	91,4	91,8	92,3
	300	0,39	15,5	46,5	57,5	67,7	68,9	75,3	78,6	82,2	83,6	84,7
		0,58	13,9	41,6	55,1	64,7	64,2	70,4	72,7	76,4	77,9	79,4
	500	0,39	10,3	31,0	42,8	54,8	57,1	64,7	69,8	75,4	78,0	79,4
		0,58	8,4	25,3	37,5	48,1	48,6	55,8	58,9	63,6	65,8	68,1
	750	0,39	6,7	20,1	30,4	42,6	44,9	54,1	60,2	67,2	71,0	73,0
		0,58	5,5	16,6	27,1	38,0	39,0	47,6	52,1	57,8	60,6	63,3
	1 000	0,39	4,9	14,6	22,7	33,9	36,3	46,3	53,1	61,0	65,7	68,0
		0,58	4,0	11,9	20,1	30,0	31,2	40,2	45,5	52,3	55,5	58,5
60° to 75°	100	0,40	21,0	63,1	69,9	74,6	74,7	77,5	78,7	80,1	80,7	82,0
		0,48	17,1	51,3	57,6	61,7	61,7	64,2	65,4	67,0	67,7	69,9
	300	0,40	11,9	35,8	46,3	55,6	56,5	61,7	64,5	68,0	69,7	71,5
		0,48	9,4	28,1	36,3	42,8	43,0	47,1	49,3	52,2	53,6	56,5
	500	0,40	7,3	21,9	32,4	43,7	45,5	52,6	56,7	61,3	63,7	66,0
		0,48	6,5	19,5	29,2	38,0	38,7	44,4	47,5	51,5	53,6	56,7
	750	0,40	4,6	13,8	21,4	32,1	34,3	43,0	48,4	54,1	57,1	59,7
		0,48	3,7	11,0	17,7	25,7	27,0	32,8	36,2	40,5	42,7	46,4
	1 000	0,40	3,3	10,0	15,6	24,4	26,2	35,7	42,1	49,0	52,6	55,7
		0,48	2,7	8,1	13,0	20,0	21,3	28,0	32,0	36,9	39,5	43,5

[a] Corresponds to a south facade in the southern hemisphere.

A.3.2.5 Determination of daylight supply factor for sunshading activated $F_{D,s,SA,j}$

Facade system solutions with an activated solar and/or glare protection can be classified according to Table A.10 in a simplified way.

Table A.10 — System solutions (values to be applied for the period $t_{rel,D,SA,j}$)

System solution (to be used for the period $t_{rel,D,SA,j}$)		$F_{D,s,SA,j}$			
		Classification of daylight availability			
		None	Low	Medium	Strong
1	Glare protection only: Systems which provide glare protection in compliance with the regulations applying to the respective utilization profile, e. g. regulations for computer terminal workplaces[2]. This includes manually operated venetian blinds, shutters and comparable systems	—	0,1	0,2	0,3
2	Automatically-operated protection against solar radiation and glare: Devices to protect against solar radiation and/or glare and which can be moved in relation to the amount of daylight available. Venetian blinds which are automatically opened slightly after being lowered, so that transmittance is greater than that of the fully closed blinds.	—	0,2	0,43	0,55
3	Light-guiding systems	—	0,3	0,65	0,8
4	No protection against solar radiation and shades. NOTE Only applicable for areas being evaluated to which no special regulations or provisions such as the regulations for computer terminal workplaces apply.	—	0,6	0,75	0,8

Light-guiding system solutions, line 3 of Table A.10, can be assumed to include solutions of type 1 with additional light-guiding functions:

— Venetian blinds in cut-off operating mode: In the so-called “cut-off” mode, the louvres of the blinds are directed in relation to the incident sunlight in such a way that direct sunlight is just prevented from passing through, but diffuse daylight can enter. Furthermore, these systems generally permit visual contact to the surroundings for a large part of the operating time. Appropriate control systems which move the louvres in relation to the solar radiation profile angle shall be installed. The sun profile angle is the projection of the altitude angle of the sun onto a vertical plane which is perpendicular to the plane of the facade surface.

— Light-guiding glass: Facade systems using glass components which transmit at least 30 % of the incident direct sunlight into the upper quarter of the space when lit under an altitude of 35° (measured from the normal of the facade plane) at a sun-facade azimuth of zero. As a general rule, not more than 1/3 of the transparent facade openings should be equipped with such systems to prevent overheating of the respective space. Light-guiding glass shall be combined with other solar radiation protection and/or glare protection systems installed in the lower section of the facade area. However, no solar and/or glare protection devices can be installed in front of the light-guiding components described below.

— Daylight-guiding external Venetian blinds: These have diffuse surfaces and the louvres of the upper and lower sections of the blinds are at different angles. The upper section of the blind shall not be higher than 1/3 and not lower than 1/4 of the total blind length and the system shall be equipped with control devices.

— Daylight-guiding internal Venetian blinds between glazing layers or in the air-space (gap) of glazed double facades: These have highly reflective or mirror-finished surfaces and the louvres of the upper and lower sections of the blinds are at different angles. The upper section of the blind shall not be higher than 1/3 and not lower than 1/4 of the total blind length and the system shall be equipped with control devices.

No solar and/or glare protection devices can be installed in front of the light-guiding components listed in Table A.10.

A.4 Daylight supply factor for rooflights

A.4.1 General

As in the method applied for vertical facades, the first evaluation step for rooflights is to classify the daylight availability via the daylight factor. Then the daylight supply factors can be determined for different maintained illuminance values, different orientations and slope angles of the glazed roof openings and locations and climates.

A.4.2 Daylight availability factor

An approximate value of the mean daylight factor of spaces equipped with rooflights can be calculated using Formula (A.18).

$$\bar{D}_j = D_a \, \tau_{D65} \, k_1 \, k_2 \, k_3 \, \frac{\sum A_{Ca}}{A_D} \eta_R \text{ in } \% \quad \text{(A.18)}$$

where

A_{Ca} is the area of the rooflights (raw roof opening dimensions);

A_D is the floor area which is lit by daylight in the space being evaluated;

D_a is the external daylight factor;

τ_{D65} is the transmittance of the diffusive rooflight glazing for daylight D65;

k_1 is the reduction factor for frames and subdivisions of the glazing;

k_2 is the reduction factor for pollution of the glazing;

k_3 is the reduction factor for non-vertical light incidence on the skylight (usually, 0,85 is considered to be adequate);

η_R is the value of utilance as listed in Table A.13 and Table A.14

Formula (A.18) combines the calculation stages 1 (classification of daylight availability) and 2 (description of the facade characteristics) of the three-stage calculation approach in one single calculation step. This method is also applicable for skylights with transparent glazing. As a supplement to the typical transmittance values given in Table A.6, Table A.11 contains a list of transmittance values of components frequently used in rooflights.

Table A.11 — Typical values of the transmittance τ_{D65}, U, and g of components frequently used in rooflight construction

Type	Construction/Composition	Colour/type	U W/(m^2 · K)	$g\perp$	τ_{D65}
Sky dome	Acrylic sheet, single-shell	clear	5,4	0,85	0,92
	Acrylic sheet, single-shell	opal	5,4	0,80	0,83
	Acrylic sheet, double-shell	clear/clear	2,7	0,78	0,80
	Acrylic sheet, double-shell	opal/clear	2,7	0,72	0,73
	Acrylic sheet, triple-shell	clear/clear/clear	1,8	0,66	0,68
	Acrylic sheet, triple-shell	opal/opal/clear	1,8	0,64	0,60
	PMMA, single-shell	clear	5,4	0,88	0,92
	PMMA, single-shell	opal	5,4	0,78	0,79
	PMMA, single-shell	coated	5,4	0,38	0,51
	PMMA, double-shell	clear/clear	2,8	0,77	0,84
	PMMA, double-shell	opal/clear	2,8	0,68	0,71
	PMMA, double-shell	opal/opal	2,8	0,64	0,59
	PMMA, double-shell	coated/clear	2,8	0,32	0,47
	PMMA, triple-shell	clear/clear/clear	1,7	0,70	0,79
Strip sky-light	Polycarbonate multiwall double-wall sheet, 6 mm	clear	3,6	0,86	0,82
	Polycarbonate multiwall double-wall sheet, 6 mm	opal	3,6	0,78	0,64
	Polycarbonate multiwall double-wall sheet, 8 mm	clear	3,3	0,81	0,81
	Polycarbonate multiwall double-wall sheet, 8 mm	opal	3,3	0,70	0,62
	Polycarbonate multiwall double-wall sheet, 10 mm	clear	3,1	0,85	0,80
	Polycarbonate multiwall double-wall sheet, 10 mm	opal	3,1	0,70	0,50
	Polycarbonate multiwall triple-wall sheet, 10 mm	clear	3,0	0,69	0,73
	Polycarbonate multiwall triple-wall sheet, 10 mm	opal	3,0	0,62	0,52
	Polycarbonate multiwall four-wall sheet, 10 mm	opal	2,5	0,59	0,50
	Polycarbonate multiwall triple-wall sheet, 16 mm	clear	2,4	0,69	0,72
	Polycarbonate multiwall triple-wall sheet, 16 mm	opal	2,4	0,55	0,48
	Polycarbonate multiwall five-wall sheet, 16 mm	opal	1,9	0,52	0,45
	Polycarbonate multiwall six-wall sheet, 16 mm	opal	1,85	0,47	0,42
	Polycarbonate multiwall five-wall sheet, 20 mm	clear	1,8	0,70	0,64
	Polycarbonate multiwall five-wall sheet, 20 mm	opal	1,8	0,46	0,44
	Polycarbonate multiwall four-wall sheet, 25 mm	clear	1,7	0,62	0,68
	Polycarbonate multiwall four-wall sheet, 25 mm	opal	1,7	0,53	0,45
	Polycarbonate multiwall six-wall sheet, 25 mm	clear	1,45	0,67	0,62
	Polycarbonate multiwall six-wall sheet, 25 mm	opal	1,45	0,46	0,44

Key

A individual roof windows, glazed,

B continuous rooflight, glazed

Table A.11 *(continued)*

Type	Construction/Composition	Colour/type	U W/(m^2 · K)	$g\perp$	τ_{D65}
Strip sky-light	PMMA multiwall double-wall sheet, 8 mm	clear	3,4	0,82	0,84
	PMMA multiwall double-wall sheet, 8 mm	opal	3,4	0,79	0,80
	PMMA multiwall double-wall sheet, 8 mm	coated	3,4	0,50	0,62
	PMMA multiwall double-wall sheet, 16 mm	clear	2,5	0,82	0,86
	PMMA multiwall double-wall sheet, 16 mm	clear, C-relief	2,5	0,81	0,85
	PMMA multiwall double-wall sheet, 16 mm	opal	2,5	0,73	0,74
	PMMA multiwall double-wall sheet, 16 mm	coated	2,5	0,40	0,50
	PMMA multiwall double-wall sheet, 16 mm	coated	2,5	0,82	0,91
	PMMA multiwall double-wall sheet, 16 mm	coated, brown	2,5	0,63	0,50
	PMMA multiwall four-wall sheet, 32 mm	clear	1,6	0,71	0,76
	PMMA multiwall four-wall sheet, 32 mm	clear, C-relief	1,6	0,69	0,74
	PMMA multiwall four-wall sheet, 32 mm	opal	1,6	0,60	0,64
	PMMA multiwall four-wall sheet, 32 mm	coated, opal	1,6	0,30	0,40
	PMMA multiwall four-wall sheet, 32 mm	coated, clear	1,6	0,50	0,45
A	4 mm float glass 16 mm air 4 mm float glass	clear double pane	2,8	0,79	0,81
A	4 mm toughened glass 16 mm Argon 4 mm float glass w. coating	clear double pane low-e	1,2	0,59	0,76
A	4 mm toughened glass 14 mm Argon 33,1 laminated float glass	clear double pane low-e	1,2	0,54	0,75
A	4 mm toughened 14 mm air 33,1 laminated float glass w. coating	clear double pane low-e, sun protection	1,2	0,27	0,42
B	Laminated glass 6,2 16 mm air, 6 mm float glass	clear	2,7	0,67	0,77
B	Laminated glass 6,2 16 mm air, 8 mm float glass	clear	2,7	0,67	0,77
B	Laminated glass 8,2 16 mm air, 6 mm float glass	clear	2,7	0,65	0,77
B	Laminated glass 8,2 16 mm air, 8 mm float glass	clear	2,7	0,65	0,76
B	Laminated glass 10,2 16 mm air, 6 mm float glass	clear	2,7	0,63	0,76
B	Laminated glass 10,2 16 mm air, 8 mm float glass	clear	2,7	0,63	0,76
B	Laminated glass 6,2 16 mm argon, 6 mm float glass	coated, silver	1,1	0,52	0,72
B	Laminated glass 6,2 16 mm argon, 8 mm float glass	coated, silver	1,1	0,52	0,71
B	Laminated glass 8,2 16 mm argon, 6 mm float glass	coated, silver	1,1	0,51	0,71

Key

A individual roof windows, glazed,

B continuous rooflight, glazed

Table A.11 *(continued)*

Type	Construction/Composition	Colour/type	U W/(m² · K)	$g\perp$	τ_{D65}
B	Laminated glass 8,2 16 mm argon, 8 mm float glass	coated, silver	1,1	0,51	0,70
B	Laminated glass 10,2 16 mm argon, 6 mm float glass	coated, silver	1,1	0,50	0,70
B	Laminated glass 10,2 16 mm argon, 8 mm float glass	coated, silver	1,1	0,49	0,70
B	6 mm toughened glass (extra clear) 18 mm Argon, 33,1 laminated float glass	clear double pane	1,5	0,61	0,79
B	6 mm toughened glass (green) 18 mm Argon, 33,1 laminated float glass	clear double pane	1,5	0,38	0,64
B	6 mm toughened glass (grey) 18 mm Argon, 33,1 laminated float glass	clear double pane	1,5	0,34	0,39
B	6 mm toughened glass (extra clear) 18 mm Argon, 44,1 laminated float glass	clear double pane	1,5	0,55	0,78

Key
A individual roof windows, glazed,
B continuous rooflight, glazed

The external daylight factor D_a (in %) is defined as:

$$D_a = \frac{E_F}{E_a} \tag{A.19}$$

where

E_F is the illuminance on the external surface of the skylight from an overcast sky;

E_a is the horizontal external illuminance from an overcast sky.

The correction factor $k_{Obl,1}$ for frames and subdivisions can be determined using Formula (A.13). The structural parts of dome skylights include the annular supports. Thus, $k_{Obl,1}$ is the ratio of the area $A_{Fs} = a_s \cdot b_s$ through which light can pass, i.e. the top opening of the annular support, minus the area of other opaque parts of the domes or strip skylights, to the area $A_{Rb} = a_{Rb} \cdot b_{Rb}$ of the raw roof opening as shown in Figure A.12.

As opposed to this, the raw roof opening area of shed rooflights does not correspond to the area of the roof plane occupied by the shed structure, as shown in Figure A.13. For these, the raw roof opening area is $A_{Ca} = h_G \cdot b_{Rb}$, where h_G is the height of the skylight opening and b_{Rb} is the width of the skylight opening. The correction factor $k_{Obl,1}$ for frames and subdivisions accounts for the other opaque parts of the skylight structure within the opening defined in this way.

Table A.12 lists external daylight factors D_a for a ground reflectance ρ_B of 0,2 and various slope angles of the shed-roof glazing.

Table A.12 — External daylight factor D_a as a function of the facade slope γ_F for a floor reflectance ρ_B of 0,2 (without building shading)

Slope γ_F degrees	$D_a = E_F/E_a$ %
0	100
30	92
45	83
60	72
90	50

The utilance η_R is calculated on the basis of the space index as determined using Formula (A.20) and the type of rooflight involved. In the calculation of η_R, h'_R is the difference between the ceiling height and the work plane height. The height of the work plane is given for individual utilization profiles in A.8. A distinction is made between the dome skylights shown in Figure A.12 and the shed rooflights shown in Figure A.13. Strip skylights are treated as a special dome skylight design. For strip skylights with a side ratio a_s/b_s of more than 5, the utilance stated for ratio $a_s/b_s = 5$ should be assumed. The room index is defined as

$$k = \frac{a_R \cdot b_R}{h'_R \cdot (b_R + a_R)} \tag{A.20}$$

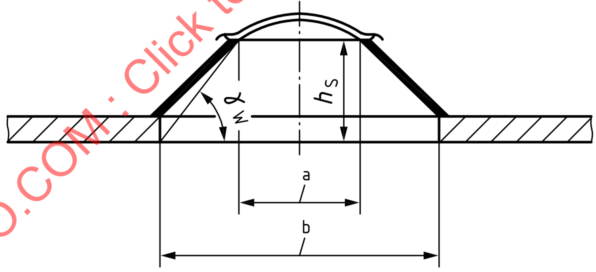
where

a_R is the room depth;

b_R is the room width;

h'_R is the height difference of ceiling and task area height.

Table A.13 and Table A.14 show utilance values for different types of dome and shed rooflight geometries.



Key

a_s clear length of the aperture in m

b_s clear width of the aperture in m

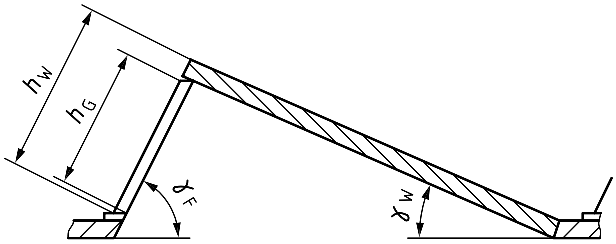
a_{Ca} clear length of the upstand/well in m

b_{Ca} clear width of the upstand/well in m

h_s height of the upstand/well in m

γ_W of the upstand/well in °

Figure A.12 — Dimensions used to describe the geometry of the annular supports of spaces with dome and strip skylights



Key

h_s a_s and b_s in m
h_W total height of construction in m
γ_W angle of roof to horizontal in °
γ_F angle of glazing to horizontal in °

Figure A.13 — Dimensions used to describe the geometry of shed rooflights

Table A.13 — Dome skylight utilances η_R, as a function of the space index k and the geometry parameters of the annular support design

a_s/b_s	1			2			5			1			2			5		
h_s/b_s	0,25			0,25			0,25			0,5			0,5			0,5		
γ_w	30°	60°	90°	30°	60°	90°	30°	60°	90°	30°	60°	90°	30°	60°	90°	30°	60°	90°
k	η_R																	
0,6	0,40	0,41	0,38	0,40	0,40	0,39	0,41	0,41	0,40	0,40	0,41	0,36	0,40	0,41	0,37	0,42	0,43	0,39
0,8	0,53	0,54	0,50	0,53	0,54	0,51	0,54	0,55	0,52	0,53	0,55	0,46	0,53	0,55	0,49	0,55	0,57	0,51
1,0	0,59	0,60	0,56	0,59	0,60	0,57	0,60	0,61	0,59	0,60	0,61	0,51	0,60	0,61	0,54	0,62	0,66	0,56
1,25	0,68	0,69	0,64	0,68	0,69	0,66	0,69	0,70	0,67	0,69	0,69	0,58	0,69	0,70	0,62	0,71	0,72	0,64
1,5	0,75	0,75	0,69	0,75	0,75	0,71	0,76	0,76	0,72	0,76	0,75	0,63	0,76	0,76	0,67	0,78	0,78	0,69
2,0	0,83	0,83	0,77	0,83	0,83	0,79	0,84	0,84	0,80	0,84	0,82	0,69	0,84	0,83	0,73	0,87	0,85	0,75
2,5	0,89	0,88	0,81	0,89	0,88	0,84	0,90	0,89	0,85	0,90	0,87	0,73	0,90	0,88	0,77	0,92	0,90	0,79
3,0	0,93	0,92	0,85	0,93	0,92	0,87	0,94	0,93	0,88	0,94	0,90	0,76	0,94	0,91	0,81	0,96	0,93	0,86
4,0	0,98	0,96	0,90	0,98	0,97	0,92	0,99	0,98	0,93	0,99	0,95	0,80	0,98	0,96	0,85	1,00	0,98	0,87
5,0	1,02	1,00	0,92	1,02	1,00	0,95	1,03	1,01	0,96	1,02	0,97	0,82	1,02	0,99	0,87	1,04	1,01	0,89

Table A.14 — Shed rooflight utilances η_R, as a function of the space index k and the geometry parameters

h_G/h_W	1													0,5												
γ_F	30				45	60				90				30				45	60				90			
γ_w	30°	45°	60°	75°	45°	30°	45°	60°	75°	30°	45°	60°	75°	30°	45°	60°	75°	45°	30°	45°	60°	75°	30°	45°	60°	75°
k	η_R																									
0,6	0,39	0,39	0,41	0,40	0,37	0,34	0,35	0,36	0,35	0,29	0,30	0,31	0,31	0,38	0,39	0,39	0,40	0,36	0,33	0,34	0,35	0,36	0,29	0,29	0,30	0,30
0,8	0,51	0,52	0,53	0,50	0,49	0,44	0,45	0,46	0,44	0,37	0,39	0,39	0,38	0,50	0,51	0,52	0,51	0,48	0,43	0,44	0,45	0,44	0,37	0,37	0,38	0,38
1,0	0,57	0,58	0,58	0,55	0,55	0,50	0,52	0,51	0,49	0,44	0,45	0,45	0,44	0,56	0,57	0,57	0,56	0,53	0,49	0,50	0,51	0,50	0,43	0,44	0,44	0,44
1,25	0,66	0,66	0,65	0,62	0,62	0,58	0,59	0,58	0,55	0,51	0,51	0,51	0,49	0,65	0,65	0,65	0,64	0,61	0,57	0,58	0,58	0,56	0,50	0,51	0,50	0,50
1,5	0,72	0,72	0,71	0,67	0,68	0,64	0,64	0,63	0,60	0,56	0,56	0,56	0,54	0,71	0,71	0,71	0,69	0,67	0,62	0,63	0,63	0,61	0,55	0,56	0,55	0,55
2,0	0,80	0,79	0,77	0,73	0,75	0,72	0,71	0,69	0,66	0,64	0,63	0,62	0,60	0,79	0,79	0,78	0,76	0,75	0,71	0,71	0,70	0,68	0,62	0,63	0,62	0,61
2,5	0,85	0,84	0,81	0,77	0,80	0,77	0,76	0,73	0,70	0,69	0,68	0,66	0,64	0,84	0,84	0,83	0,80	0,80	0,76	0,76	0,75	0,72	0,68	0,68	0,67	0,65
3,0	0,88	0,88	0,84	0,80	0,83	0,81	0,79	0,76	0,72	0,72	0,71	0,69	0,67	0,88	0,88	0,86	0,83	0,84	0,80	0,80	0,78	0,75	0,72	0,71	0,70	0,68
4,0	0,94	0,92	0,88	0,84	0,87	0,85	0,83	0,80	0,76	0,77	0,75	0,73	0,70	0,93	0,93	0,91	0,87	0,88	0,85	0,84	0,82	0,79	0,77	0,76	0,75	0,72
5,0	0,97	0,95	0,91	0,87	0,90	0,89	0,86	0,82	0,78	0,80	0,78	0,75	0,73	0,97	0,96	0,93	0,90	0,92	0,89	0,88	0,85	0,81	0,80	0,79	0,77	0,75

Daylight availability is classified according to the criteria shown in Table A.15.

The daylight supply factor $F_{D,s,SNA,j}$ can be calculated using computer-based tools or using the regression-based compound method in A.4.2.

Table A.15 — Classification of daylight availability as a function of the daylight factor $\bar{D}_j$

Classification criterion $\bar{D}_j$	Classification of daylight availability
$7 \leq \bar{D}_j$ [a]	Good
$4 \leq \bar{D}_j < 7$ %	Average
$2 \leq \bar{D}_j < 4$ %	Poor
$0 \leq \bar{D}_j < 2$ %	None

[a] In accordance with DIN 5034-6[5], values of $\bar{D}_j > 10$ % should be avoided due to the danger of overheating.

If a daylight factor which has been calculated using another validated method is known, this can be used instead of the value calculated by Formula (A.18) when classifying daylight availability according to Table A.15. In this case, the daylight factor is to be determined as the mean value on the work plane.

A.4.3 Daylight supply factor

Table A.16 provides a set of values of $F_{D,s,j}$ for rooflights for different locations and climates. Movable shading devices are not taken into consideration here. For maintained illuminances $\bar{E}_m$ of less than 300 lx, daylight supply factor $F_{D,s,j}$ values for $\bar{E}_m = 300$ lx should be used, and for maintained illuminances $\bar{E}_m$ of greater than 750 lx, the $F_{D,s,j}$ values for $\bar{E}_m = 750$ lx should be used. In case $\bar{E}_m$ is not listed in Table A.16 and Table A.17, the values for $F_{D,s,j}$ and $F_{D,C,j}$ are obtained by linear interpolation between the two adjacent $\bar{E}_m$ values.

Table A.16 — Daylight supply factor $F_{D,s,j}$ of spaces with skylights as a function of the daylight availability classification, the maintained illuminance $\bar{E}_m$, facade orientation and incline, location γ, and climate (H_{dir}/H_{glob})

Geographic location γ	H_{dir}/H_{glob}	Orientation	$\bar{E}_m$	Poor[a]			Average[a]			Good[a]		
				300 lx	500 lx	750 lx	300 lx	500 lx	750 lx	300 lx	500 lx	750 lx
			Surface slope	$F_{D,s,j}$								
0° to 15°	0,34	Horizontal	0°	0,97	0,92	0,84	0,99	0,98	0,99	1,00	0,99	0,98
		South	30°	0,96	0,88	0,78	0,99	0,97	0,99	1,00	0,99	0,97
			45°	0,93	0,83	0,70	0,98	0,95	0,98	1,00	0,98	0,95
			60°	0,89	0,74	0,58	0,97	0,91	0,96	0,99	0,96	0,91
			90°	0,62	0,42	0,30	0,85	0,68	0,84	0,94	0,84	0,69
		East/West	30°	0,95	0,87	0,76	0,99	0,96	0,99	1,00	0,99	0,96
			45°	0,91	0,80	0,66	0,98	0,93	0,98	1,00	0,98	0,94
			60°	0,86	0,71	0,55	0,96	0,89	0,95	0,99	0,95	0,89
			90°	0,61	0,42	0,31	0,84	0,66	0,83	0,93	0,83	0,68
		North	30°	0,96	0,88	0,77	0,99	0,97	0,99	1,00	0,99	0,97
			45°	0,93	0,82	0,68	0,98	0,95	0,98	1,00	0,98	0,95
			60°	0,88	0,72	0,55	0,97	0,90	0,96	0,99	0,96	0,91
			90°	0,61	0,40	0,28	0,85	0,67	0,84	0,94	0,84	0,68
	0,66	Horizontal	0°	1,00	0,99	0,97	1,00	1,00	1,00	1,00	1,00	1,00
		South	30°	1,00	0,99	0,96	1,00	1,00	1,00	1,00	1,00	1,00
			45°	0,99	0,97	0,92	1,00	1,00	1,00	1,00	1,00	1,00
			60°	0,98	0,93	0,85	1,00	0,99	1,00	1,00	1,00	0,99
			90°	0,79	0,64	0,50	0,94	0,83	0,93	0,99	0,93	0,84
		East/West	30°	0,99	0,96	0,92	1,00	0,99	1,00	1,00	1,00	0,99
			45°	0,94	0,90	0,84	0,98	0,95	0,98	1,00	0,98	0,95
			60°	0,88	0,82	0,75	0,95	0,90	0,94	0,99	0,94	0,90
			90°	0,72	0,61	0,53	0,85	0,75	0,84	0,93	0,84	0,76
		North	30°	0,98	0,95	0,90	1,00	0,99	1,00	1,00	1,00	0,99
			45°	0,94	0,87	0,77	0,99	0,95	0,98	1,00	0,98	0,95
			60°	0,83	0,71	0,59	0,94	0,85	0,93	0,99	0,93	0,85
			90°	0,56	0,38	0,27	0,79	0,61	0,77	0,91	0,77	0,63

[a] The following daylight factors $D_{RB,j}$ of the raw carcass opening were used to calculate these values:

— poor: 3 %;

— average: 5,5 %;

— good: 8,5 %.

Table A.16 *(continued)*

Geographic location γ	H_{dir}/H_{glob}	Orientation	$\bar{E}_m$	Poor[a]			Average[a]			Good[a]		
				300 lx	500 lx	750 lx	300 lx	500 lx	750 lx	300 lx	500 lx	750 lx
			Surface slope	$F_{D,s,j}$								
15° to 30°	0,34	Horizontal	0°	0,95	0,89	0,79	0,99	0,96	0,99	1,00	0,99	0,96
		South	30°	0,93	0,85	0,74	0,98	0,95	0,98	0,99	0,98	0,95
			45°	0,91	0,80	0,67	0,97	0,92	0,97	0,99	0,97	0,93
			60°	0,86	0,72	0,57	0,95	0,88	0,94	0,98	0,94	0,89
			90°	0,62	0,44	0,32	0,84	0,67	0,82	0,92	0,82	0,69
		East/West	30°	0,93	0,84	0,72	0,98	0,94	0,98	0,99	0,98	0,94
			45°	0,89	0,77	0,62	0,97	0,91	0,96	0,99	0,96	0,92
			60°	0,83	0,67	0,51	0,94	0,86	0,93	0,98	0,93	0,87
			90°	0,58	0,40	0,29	0,81	0,63	0,80	0,91	0,80	0,64
		North	30°	0,93	0,83	0,71	0,98	0,94	0,98	0,99	0,98	0,94
			45°	0,88	0,75	0,60	0,97	0,91	0,96	0,99	0,96	0,91
			60°	0,82	0,64	0,48	0,94	0,85	0,93	0,98	0,93	0,86
			90°	0,53	0,33	0,22	0,80	0,59	0,78	0,91	0,78	0,61
	0,58	Horizontal	0°	0,99	0,97	0,93	1,00	0,99	1,00	1,00	1,00	0,99
		South	30°	0,99	0,96	0,92	1,00	0,99	1,00	1,00	1,00	0,99
			45°	0,98	0,95	0,89	1,00	0,99	1,00	1,00	1,00	0,99
			60°	0,97	0,92	0,84	0,99	0,98	0,99	1,00	0,99	0,98
			90°	0,82	0,68	0,53	0,96	0,87	0,95	0,99	0,95	0,88
		East/West	30°	0,96	0,91	0,85	0,99	0,97	0,99	1,00	0,99	0,97
			45°	0,92	0,84	0,76	0,98	0,94	0,98	1,00	0,98	0,94
			60°	0,88	0,76	0,67	0,97	0,90	0,96	0,99	0,96	0,90
			90°	0,69	0,54	0,43	0,88	0,73	0,86	0,96	0,86	0,74
		North	30°	0,97	0,92	0,84	0,99	0,97	0,99	1,00	0,99	0,98
			45°	0,91	0,80	0,70	0,98	0,93	0,98	1,00	0,98	0,93
			60°	0,84	0,69	0,56	0,96	0,87	0,95	0,99	0,95	0,87
			90°	0,56	0,35	0,24	0,83	0,62	0,81	0,94	0,81	0,64

Classification of daylight availability (column group heading above Poor, Average, Good).

[a] The following daylight factors $D_{RB,j}$ of the raw carcass opening were used to calculate these values:

— poor: 3 %;

— average: 5,5 %;

— good: 8,5 %.

Table A.16 *(continued)*

Geographic location γ	H_{dir}/H_{glob}	Orientation	$\bar{E}_m$	Classification of daylight availability								
				Poor[a]			Average[a]			Good[a]		
				300 lx	500 lx	750 lx	300 lx	500 lx	750 lx	300 lx	500 lx	750 lx
			Surface slope	$F_{D,s,j}$								
30° to 45°	0,36	Horizontal	0°	0,95	0,90	0,82	0,98	0,96	0,98	0,99	0,98	0,96
		South	30°	0,94	0,87	0,78	0,97	0,95	0,97	0,98	0,97	0,95
			45°	0,92	0,83	0,71	0,97	0,93	0,96	0,98	0,96	0,94
			60°	0,89	0,76	0,62	0,95	0,90	0,95	0,97	0,95	0,91
			90°	0,67	0,50	0,38	0,87	0,72	0,86	0,93	0,86	0,74
		East/West	30°	0,92	0,84	0,73	0,97	0,93	0,96	0,98	0,96	0,93
			45°	0,88	0,77	0,64	0,95	0,90	0,95	0,98	0,95	0,91
			60°	0,83	0,68	0,53	0,93	0,86	0,92	0,97	0,92	0,86
			90°	0,59	0,41	0,30	0,82	0,64	0,80	0,91	0,80	0,66
		North	30°	0,92	0,83	0,71	0,97	0,93	0,97	0,98	0,97	0,94
			45°	0,87	0,74	0,60	0,95	0,89	0,95	0,98	0,95	0,90
			60°	0,81	0,64	0,47	0,93	0,84	0,92	0,97	0,92	0,85
			90°	0,52	0,32	0,22	0,79	0,58	0,77	0,90	0,77	0,59
	0,71	Horizontal	0°	0,95	0,93	0,90	0,97	0,96	0,97	0,98	0,97	0,96
		South	30°	0,96	0,94	0,90	0,97	0,96	0,97	0,97	0,97	0,96
			45°	0,95	0,92	0,89	0,97	0,95	0,97	0,97	0,97	0,96
			60°	0,94	0,90	0,86	0,96	0,95	0,96	0,97	0,96	0,95
			90°	0,84	0,73	0,60	0,92	0,87	0,92	0,95	0,92	0,87
		East/West	30°	0,87	0,81	0,75	0,93	0,88	0,93	0,97	0,93	0,88
			45°	0,80	0,72	0,66	0,89	0,81	0,88	0,95	0,88	0,82
			60°	0,73	0,64	0,56	0,85	0,75	0,83	0,92	0,83	0,75
			90°	0,55	0,43	0,33	0,70	0,57	0,69	0,82	0,69	0,58
		North	30°	0,86	0,77	0,69	0,94	0,87	0,93	0,97	0,93	0,88
			45°	0,75	0,64	0,55	0,87	0,77	0,86	0,95	0,86	0,77
			60°	0,64	0,51	0,38	0,81	0,67	0,79	0,91	0,79	0,68
			90°	0,34	0,20	0,13	0,58	0,37	0,55	0,76	0,55	0,38

[a] The following daylight factors $D_{RB,j}$ of the raw carcass opening were used to calculate these values:

— poor: 3 %;

— average: 5,5 %;

— good: 8,5 %.

Table A.16 *(continued)*

Geographic location γ	H_{dir}/H_{glob}	Orientation	$\bar{E}_m$	Classification of daylight availability								
				Poor[a]			Average[a]			Good[a]		
				300 lx	500 lx	750 lx	300 lx	500 lx	750 lx	300 lx	500 lx	750 lx
			Surface slope	$F_{D,s,j}$								
45° to 60°	0,39	Horizontal	0°	0,85	0,76	0,66	0,91	0,86	0,91	0,94	0,91	0,86
		South	30°	0,83	0,73	0,64	0,90	0,84	0,89	0,93	0,89	0,85
			45°	0,79	0,69	0,59	0,88	0,81	0,87	0,92	0,87	0,82
			60°	0,74	0,63	0,52	0,85	0,77	0,84	0,90	0,84	0,77
			90°	0,57	0,45	0,35	0,73	0,60	0,71	0,81	0,71	0,61
		East/West	30°	0,80	0,69	0,58	0,89	0,82	0,88	0,93	0,88	0,83
			45°	0,75	0,62	0,50	0,87	0,78	0,86	0,91	0,86	0,78
			60°	0,68	0,53	0,41	0,83	0,71	0,81	0,89	0,81	0,72
			90°	0,46	0,32	0,23	0,66	0,49	0,64	0,78	0,64	0,51
		North	30°	0,78	0,66	0,55	0,88	0,80	0,87	0,93	0,87	0,81
			45°	0,72	0,57	0,44	0,85	0,75	0,84	0,91	0,84	0,76
			60°	0,63	0,45	0,31	0,80	0,67	0,79	0,88	0,79	0,68
			90°	0,37	0,23	0,15	0,60	0,41	0,58	0,76	0,58	0,42
	0,58	Horizontal	0°	0,91	0,85	0,77	0,95	0,91	0,94	0,96	0,94	0,92
		South	30°	0,90	0,84	0,77	0,94	0,91	0,94	0,96	0,94	0,91
			45°	0,88	0,81	0,73	0,93	0,90	0,93	0,95	0,93	0,90
			60°	0,86	0,77	0,68	0,92	0,87	0,91	0,94	0,91	0,87
			90°	0,78	0,68	0,58	0,88	0,81	0,88	0,92	0,88	0,82
		East/West	30°	0,84	0,75	0,66	0,92	0,86	0,91	0,95	0,91	0,86
			45°	0,78	0,67	0,57	0,88	0,80	0,87	0,94	0,87	0,81
			60°	0,71	0,59	0,48	0,84	0,74	0,83	0,91	0,83	0,75
			90°	0,51	0,38	0,28	0,69	0,54	0,67	0,81	0,67	0,55
		North	30°	0,82	0,72	0,61	0,91	0,84	0,90	0,95	0,90	0,84
			45°	0,74	0,60	0,48	0,87	0,77	0,86	0,93	0,86	0,77
			60°	0,64	0,46	0,31	0,81	0,67	0,79	0,90	0,79	0,68
			90°	0,34	0,21	0,14	0,58	0,38	0,56	0,75	0,56	0,39

[a] The following daylight factors $D_{RB,j}$ of the raw carcass opening were used to calculate these values:

— poor: 3 %;

— average: 5,5 %;

— good: 8,5 %.

Table A.16 *(continued)*

Geographic location γ	H_{dir}/H_{glob}	Orientation	$\bar{E}_m$ / Surface slope	Classification of daylight availability: Poor[a] 300 lx	Poor[a] 500 lx	Poor[a] 750 lx	Average[a] 300 lx	Average[a] 500 lx	Average[a] 750 lx	Good[a] 300 lx	Good[a] 500 lx	Good[a] 750 lx
				$F_{D,s,j}$								
60° to 75°	0,40	Horizontal	0°	0,63	0,55	0,46	0,69	0,64	0,69	0,73	0,69	0,65
		South	30°	0,64	0,55	0,46	0,70	0,65	0,69	0,72	0,69	0,66
			45°	0,62	0,52	0,43	0,69	0,63	0,68	0,71	0,68	0,64
			60°	0,58	0,47	0,39	0,66	0,60	0,66	0,70	0,66	0,60
			90°	0,44	0,35	0,27	0,57	0,47	0,56	0,64	0,56	0,47
		East/West	30°	0,58	0,49	0,39	0,67	0,60	0,66	0,71	0,66	0,61
			45°	0,54	0,42	0,33	0,64	0,56	0,63	0,69	0,63	0,57
			60°	0,48	0,35	0,27	0,61	0,51	0,59	0,67	0,59	0,51
			90°	0,31	0,21	0,15	0,47	0,33	0,45	0,57	0,45	0,34
		North	30°	0,55	0,45	0,34	0,64	0,57	0,63	0,70	0,63	0,58
			45°	0,48	0,34	0,24	0,61	0,51	0,60	0,67	0,60	0,52
			60°	0,40	0,26	0,17	0,56	0,43	0,54	0,64	0,54	0,44
			90°	0,23	0,14	0,09	0,39	0,25	0,37	0,52	0,37	0,25
	0,49	Horizontal	0°	0,65	0,58	0,51	0,70	0,66	0,69	0,72	0,69	0,66
		South	30°	0,65	0,60	0,53	0,69	0,66	0,69	0,70	0,69	0,67
			45°	0,64	0,58	0,51	0,68	0,65	0,68	0,69	0,68	0,65
			60°	0,62	0,54	0,48	0,66	0,63	0,66	0,68	0,66	0,63
			90°	0,52	0,43	0,35	0,61	0,54	0,60	0,64	0,60	0,54
		East/West	30°	0,59	0,51	0,42	0,67	0,61	0,67	0,71	0,67	0,62
			45°	0,55	0,45	0,36	0,65	0,57	0,64	0,70	0,64	0,57
			60°	0,50	0,38	0,30	0,61	0,52	0,60	0,67	0,60	0,52
			90°	0,33	0,23	0,17	0,49	0,36	0,47	0,58	0,47	0,37
		North	30°	0,54	0,44	0,35	0,64	0,56	0,63	0,70	0,63	0,56
			45°	0,46	0,33	0,23	0,59	0,49	0,58	0,67	0,58	0,49
			60°	0,38	0,24	0,16	0,54	0,40	0,52	0,63	0,52	0,41
			90°	0,22	0,13	0,09	0,38	0,24	0,36	0,51	0,36	0,25

[a] The following daylight factors $D_{RB,j}$ of the raw carcass opening were used to calculate these values:

— poor: 3 %;

— average: 5,5 %;

— good: 8,5 %.

A.4.4 Daylight supply factor for windows in sloped roofs

In the case of rooms with windows in sloping roofs, the rooms being considered have to be adapted to equivalent rooms with either vertical facade windows or roof lights. The deciding factor for this is the roof slope angle. The roof slope angle is measured with respect to the horizontal.

The following rules should be applied.

a) For roof slope angles larger or equal to 75° the model specified in A.3 for vertical facade windows shall be used.

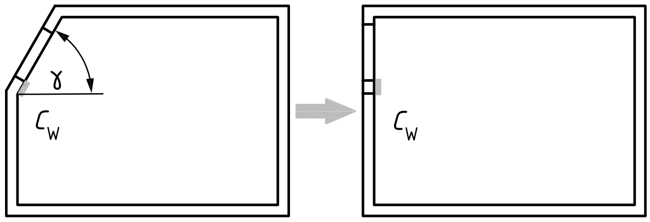
b) For slope angles smaller than 75° the model specified in A.4 for roof lights shall be used after a geometric adaptation of the room height and the window size in the equivalent room.

The diagrams in Figure A.14 and Figure A.15 show the process for adapting the room height and the window size for these two possibilities.

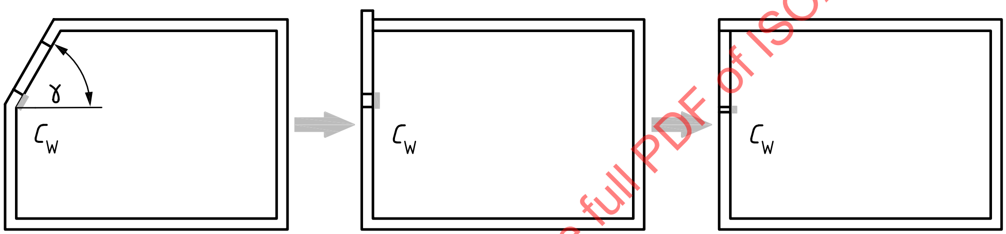
All further steps for the calculation of the daylight supply factor shall be according to the chosen model described above, where details for:

— vertical facade windows are in A.3,

— roof lights are in A.4.



a) The window is rotated to the vertical and fits without further adjustment



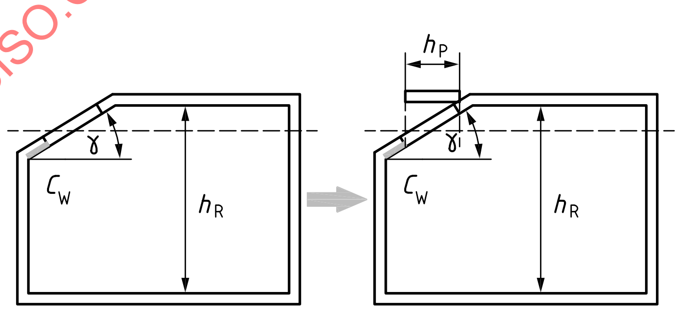
b) The window is rotated to the vertical but then protrudes above the ceiling of the room. C_w is reduced until the window fits within the room

Key

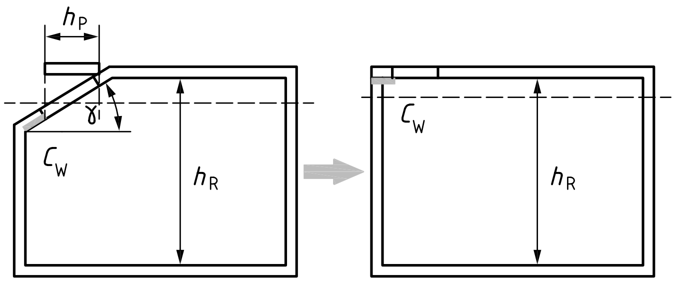
C_w is the distance between the beginning of the sloped roof and the window (m)

γ is the slope angle of the roof (°)

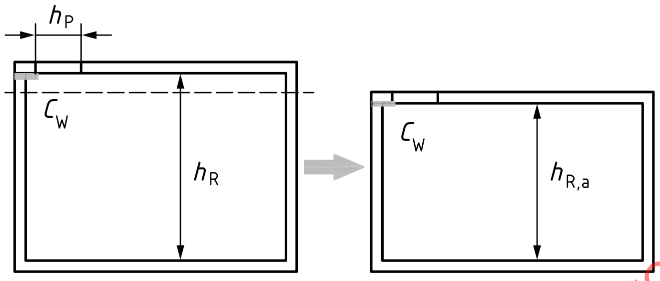
Figure A.14 — Proceeding of geometric adaption for sloped roof windows to vertical facade window (procedure A)



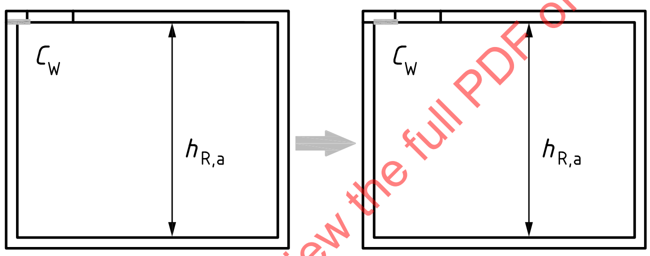
a) The window height is adjusted to h_P, the projected height of the window in the horizontal plane



b) **The resized window is rotated to the horizontal**



c) The room height is adjusted to $h_{R,a}$, based upon the midpoint of the inner surface of the original window height



d) The horizontal window is moved so that C_w is fully within the room

Key

h_R	is the room height (m)
C_w	is the distance between the beginning of the sloped roof and the window (m)
h_P	is the projected height of the window (m)
γ	is the slope angle of the roof (°)
$h_{R,a}$	is the adjusted room height (m)

Figure A.15 — Proceeding of geometric adaption for sloped roof windows to roof light (procedure B)

A.5 Daylight responsive control systems

The effects taken into consideration here relate to the characteristics of the electric lighting controls deployed to supplement the available daylight to achieve the required illuminance. Control systems which control or regulate the transmission of light through the facades are not discussed here. The approximate effects of the latter type of system are included in the evaluations described in Table A.10.

The correction factor $F_{D,c,j}$ for daylight-responsive control systems is a function of:

a) the type of control involved;

b) the daylight availability classification of the area being evaluated.

Where open-loop or closed-loop controls are used, a distinction is made as to whether the controls:

— operate automatically and autonomously, i.e. without processing information from other systems; or

— operate in a system network, i.e. can utilize information from other systems (installation bus systems or building management systems).

Electric lighting control systems are distinguished according to:

— whether they are controlled manually; or

— controlled automatically to adjust the electric light intensity to achieve the specified maintained illuminance.

An additional distinction is made between:

i) stand-alone systems, of which there are two types:

  — systems which turn off the electric lighting during operating times (if daylight availability is adequate);

  — systems which dim the electric lighting system to the lowest possible intensity during operating times without actually switching the system off.

ii) Installation bus systems and building management systems.

Table A.17 provides correction factors $F_{\text{D,c},j}$ to rate daylight responsive control systems.

Table A.17 — Correction factor $F_{\text{D,c},j}$ to account for the impact of daylight responsive control systems in a zone n, as a function of the maintained illuminance $\bar{E}_{\text{m}}$ and the daylight availability classification

Type of control			$F_{\text{D,c},j}$ as a function of daylight availability								
			Poor			Average			Good		
			300 lx	500 lx	750 lx	300 lx	500 lx	750 lx	300 lx	500 lx	750 lx
Manual			0,33	0,30	0,27	0,38	0,35	0,32	0,43	0,40	0,37
Automatic	Stand-alone	No total switch-off	0,65	0,70	0,73	0,70	0,73	0,75	0,73	0,75	0,76
		Total switch-off	0,71	0,74	0,76	0,77	0,78	0,79	0,81	0,81	0,81
	Bus systems		0,76	0,81	0,83	0,83	0,85	0,86	0,87	0,87	0,87

A.6 Monthly evaluation method

The distribution key factors $v_{\text{Month},i}$ for vertical facades are given in Table A.18. Since light-guiding systems are based on the deflection or guidance of direct light, which is more available in the summer months, separate distribution key factors as a function of the orientation are given for such systems. Table A.19 shows the values for spaces equipped with rooflights. In the summer months, daylight availability can account for 100 % of the required lighting. This means that no supplementary electric lighting is required during this period. Since the product $F_{\text{D,s},j}\ F_{\text{D,c},j}$ is weighted by monthly key factors, the differences between ($\text{v}_{\text{Month,l}}\ F_{\text{D,s},j}\ F_{\text{D,c},j} - 1$) and $\Delta F_{\text{D,s},j}$ shall be added together for all months during which $\text{v}_{\text{Month,l}}\ F_{\text{D,s},j}\ F_{\text{D,c},j}$ is greater than 1. $\Delta F_{\text{D,s},j}$ shall be equally divided up among all months during which $\text{v}_{\text{Monat,l}}\ F_{\text{D,s},j}\ F_{\text{D,c},j}$ is less than 1. Where necessary, an iteration procedure shall be applied.

Table A.18 — Monthly distribution key factors $v_{\mathrm{Month},i}$ for vertical facades

Facade system	Month, *i*											
	1	2	3	4	5	6	7	8	9	10	11	12
	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	$v_{\mathrm{Month},i}$											
Light-guiding systems according to Table A.10, South-facing	0,67	0,89	1,06	1,18	1,25	1,28	1,26	1,20	1,08	0,92	0,72	0,46
Light-guiding systems according to Table A.10, facing East or West	0,74	0,92	1,06	1,16	1,22	1,24	1,22	1,16	1,06	0,93	0,75	0,54
Others	0,85	0,97	1,06	1,12	1,16	1,17	1,15	1,11	1,04	0,94	0,81	0,66

Table A.19 — Monthly distribution key factors $v_{\mathrm{Month},i}$ for rooflights

	Month, *i*											
	1	2	3	4	5	6	7	8	9	10	11	12
	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	$v_{\mathrm{Month},i}$											
Northern Hemisphere	0,74	0,92	1,06	1,16	1,22	1,24	1,22	1,16	1,06	0,93	0,75	0,54
Southern Hemisphere	1,22	1,16	1,06	0,92	0,74	0,54	0,75	0,93	1,06	1,16	1,22	1,24

Monthly partial-load daylight operation factors $F_{\mathrm{D},j,i}$ can be derived from the calculated annual daylight supply factor.

$$F_{\mathrm{D},j,i} = \begin{cases} 1 - v_{\mathrm{Month},i}\, F_{\mathrm{D,s},j}\, F_{\mathrm{D,c},j} & \text{for } v_{\mathrm{Month,i}}\, F_{\mathrm{D,s},j}\, F_{\mathrm{D,c},j} < 1 \\ 0 & \text{otherwise} \end{cases} \tag{A.21}$$

where $v_{\mathrm{Month},i}$ is the monthly distribution key for weighting the value of $F_{\mathrm{D,s},j}$.

A method to obtain the distribution key factors $v_{\mathrm{Month},i}$ for vertical facades is provided in A.8.

A.7 Determination of day-time and night-time hours

The number of day-time and night-time hours needs to be known to be able to determine the energy need and energy use for lighting. The approximate method described below can be used in cases where the day-time and night-time hours for the types of usage listed in Table A.21 are to be determined due to deviating operating times or when a totally different type of usage is specified.

The method described below can be used to determine the number of day-time hours t_{Day} and night-time hours t_{Night} on a monthly basis for a known latitude γ and a specified beginning of usage t_{start} and end of usage t_{end}. The hours between sunrise and sunset are considered to be day-time hours.

The times $t_{\mathrm{Day},i}$ and $t_{\mathrm{Night},i}$ for each month are calculated using Formulae (A.22) and (A.23).

$$t_{\mathrm{Day},i} = N_i\, C_{\mathrm{we}}\, [(t_{\mathrm{end}} - t_{\mathrm{start}}) - (t_{\mathrm{bs},i} + t_{\mathrm{as},i})] \tag{A.22}$$

$$t_{\mathrm{Night},i} = N_i\, C_{\mathrm{we}}\, (t_{\mathrm{bs},i} + t_{\mathrm{as},i}) \tag{A.23}$$

where

N_i is the number of days in the respective month:

N_i = [31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31] with i = 1 to 12;

C_{we} is the reduction factor to account for weekends (the value of C_{we} to account for all weekends is 5/7; if no weekends are taken into consideration, C_{we} is equal to 1);

t_{start} is the time of the beginning of usage;

t_{end} is the time of the end of usage;

$t_{bs,i}$ is the usage time before sunrise;

$t_{as,i}$ is the usage time after sunset.

The times before sunrise $t_{bs,i}$ and after sunset $t_{as,i}$ are determined using Formulae (A.24) and (A.25).

$$t_{bs,i} = \begin{cases} t_{sunrise,i} - t_{start,i}, & \text{if } t_{sunrise,i} > t_{start,i} \\ 0 & \text{otherwise} \end{cases} \quad \text{(A.24)}$$

$$t_{as,i} = \begin{cases} t_{ende,i} - t_{sunset,i}, & \text{if } t_{end} > t_{sunset,i} \\ 0 & \text{otherwise} \end{cases} \quad \text{(A.25)}$$

where

t_{sunset} is the sunset time;

$t_{sunrise}$ is the sunrise time.

The time of sunrise $t_{sunrise}$ and the time of sunset t_{sunset} are calculated using Formulae (A.26) and (A.27):

$$t_{sunrise,i} = (12 - \omega_i/15°) - t_{eq}(J_i)/60 \quad \text{(A.26)}$$

$$t_{sunset,i} = (12 + \omega_i/15°) - t_{eq}(J_i)/60 \quad \text{(A.27)}$$

where

ω_i is the hour angle;

t_{eq} is the formula of time, Formula (A.30).

Formula (A.28) is used to calculate the hour angle, ω_i.

$$\omega_i = \arccos\left\{-\frac{\sin(\phi)\sin[\delta(J_i)]}{\cos(\phi)\cos[\delta(J_i)]}\right\} \quad \text{(A.28)}$$

where

ϕ is the geographical latitude of the location;

J_i is the day of the month; in this case, the 15th day of each month is used as a reference:

J_i = [15, 46, 74, 105, 135, 166, 196, 227, 258, 288, 319, 349];

δ is the declination of the sun.

Formula (A.29) is used to calculate the declination of the sun.

$$\delta(J) = 0{,}394\,8 - 23{,}255\,9 \times cos(J + 9{,}1°) - 0{,}391\,5 \times cos(2 \times J' + 5{,}4°) - 0{,}176\,4 \times cos(3 \times J' + 26{,}0°) \quad \text{(A.29)}$$

Formula (A.30) is used to determine the formula of time.

$$t_{eq}(J) = 0{,}006\,6 + 7{,}352\,5 \times cos(J + 85{,}9°) + 9{,}935\,9 \times cos(2 \times J + 108{,}9) + 0{,}338\,7 \times cos(3 \times J + 105{,}2) \quad \text{(A.30)}$$

with

$J = J \times 360°/365$

The annual day-time and night-time hours are the sum totals of the monthly values as expressed by Formulae (A.31) and (A.32) respectively:

$$t_{Day} = \sum_{i=1}^{12} t_{Day,i} \quad \text{(A.31)}$$

$$t_{Night} = \sum_{i=1}^{12} t_{Night,i} \quad \text{(A.32)}$$

Table A.20 holds for typical office operating hours precalculated times t_{Day} and t_{Night} as a function of latitude.

Table A.20 — t_{Day} and t_{Night} as a function of latitude for typical operating hours from 8 am to 5 pm, weekends excluded

Latitude	t_{Day} h	t_{Night} h
0°	2 346	0
7,5°	2 346	0
22,5°	2 346	0
37,5°	2,341	5
52,5°	2 271	75
67,5°	1 881	465
75,0°	1 629	717

A.8 Exemplary operation times of different building zone

Table A.21 — Data for usage of boundary conditions for non-residential buildings

1	2	3	4	5	6	7	8	9
Numbering	Usage	Usage and operating times						
		Beginning of usage	End of usage	Daily usage time	Annual usage days	Annual hours days per annum	Night-time usage hours per annum	Height of the work plane
		—	—	$t_{usage,d}$	$d_{usage,a}$	t_{Day}	t_{Night}	h_{Ta}
		h	h	h/d	d/a	h/a	h/a	m
1	Personal office (single occupant)	07:00	18:00	11	250	2 543	207	0,8
2	Workgroup office (two to six workplaces)	07:00	18:00	11	250	2 543	207	0,8
3	Landscaped office (seven or more workplaces)	07:00	18:00	11	250	2 543	207	0,8
4	Meeting, conference, and seminar room	07:00	18:00	11	250	2 543	207	0,8
5	Booking hall	07:00	18:00	11	250	2 543	207	0,8
6	Retail shop/department store	08:00	20:00	12	300	3 009	591	0,8
7	Retail shop/department store (food department with refrigerated products)	08:00	20:00	12	300	3 009	591	0,8
8	Classroom (school and nursery school)	08:00	15:00	7	200	1 400	0	0,8
9	Lecture room, auditorium	08:00	18:00	10	150	1 408	92	0,8
10	Hospital ward or dormitory	00:00	24:00	24	365	4 407	4 353	0,8
11	Hotel bedroom	21:00	08:00	11	365	743	3 272	0,8
12	Canteen	08:00	15:00	7	250	1 750	0	0,8
13	Restaurant	10:00	00:00	14	300	2 411	1 789	0,8
14	Kitchens in non-residential buildings	10:00	23:00	13	300	2 411	1 489	0,8
15	Kitchen – preparation room or storeroom	10:00	23:00	13	300	2 411	1 489	0,8
16	Toilets and sanitary facilities in non-residential buildings	07:00	18:00	11	250	2 543	207	0,8
17	Other habitable rooms	07:00	18:00	11	250	2 543	207	0,8
18	Auxiliary spaces (without habitable rooms)	07:00	18:00	11	250	2 543	207	0,8
19	Traffic/circulation areas	07:00	18:00	11	250	2 543	207	0
20	Storeroom, technical equipment room, archive	07:00	18:00	11	250	2 543	207	0,8
21	Server room, computer centre	00:00	24:00	24	365	4 407	4 353	0,8
22.1	Workshop, assembly, manufacturing, heavy duty work, standing work	07:00	16:00	9	230	2 018	52	0,8
22.2	Workshop, assembly, manufacturing, medium duty work, mainly standing work	07:00	16:00	9	230	2 018	52	0,8

Table A.21 *(continued)*

1	2	3	4	5	6	7	8	9
Numbering	Usage	Usage and operating times						
		Beginning of usage	End of usage	Daily usage time	Annual usage days	Annual hours days per annum	Night-time usage hours per annum	Height of the work plane
		—	—	$t_{usage,d}$	$d_{usage,a}$	t_{Day}	t_{Night}	h_{Ta}
		h	h	h/d	d/a	h/a	h/a	m
22.3	Workshop, assembly, manufacturing, simple work, mainly standing work, mainly seated work	07:00	16:00	9	230	2 018	52	0,8
23	Spectator and audience areas (theatres and event locations)	19:00	23:00	4	250	59	941	0,8
24	Foyer (theatres and event locations)	19:00	23:00	4	250	59	941	0,8
25	Stage (theatres and event locations)	13:00	23:00	10	250	1 259	1 241	0,8
26	Fair/congress building	09:00	18:00	9	150	1 258	92	0,8
27	Exhibition rooms and museums with conservation requirements	10:00	18:00	8	250	1 846	154	0,8
28	Library – reading rooms	08:00	20:00	12	300	3 009	591	0,8
29	Library – open stacks area	08:00	20:00	12	300	3 009	591	0,8
30	Library – magazine and stores	08:00	20:00	12	300	3 009	591	0,8
31	Sports hall (without public viewing area)	08:00	23:00	15	250	2 509	1 241	1
32	Garage buildings (for offices and private use)	07:00	18:00	11	250	2 543	207	0,2
33	Garage buildings (public use)	09:00	00:00	15	365	3 298	2 177	0,2
34	Sauna	10:00	22:00	12	365	2 933	1 447	0
35	Gym	08:00	23:00	15	365	3 663	1 812	0
36	Laboratory	07:00	18:00	11	250	2 543	207	1,0
37	Surgery	07:00	18:00	11	250	2 543	207	0,8
38	Special care area	00:00	24:00	24	365	4 407	4 353	0,8
39	Hallways in general nursery areas	00:00	24:00	24	365	4 407	4 353	0,2
40	Medical and therapeutical practice	08:00	18:00	10	250	2 346	154	0,8
41	Storehouses, logistic places (high-rack warehouses)	00:00	24:00	24	365	4 407	4 353	0

Annex B
(informative)

Comprehensive hourly calculation

B.1 General

This annex specifies an approach to calculate the effect of daylight on the lighting energy demand on an hourly or sub-hourly basis. Unlike the regression based annual method in Annex A this method relies on an emulation concept, as depicted in Figure B.1. Relevant quantities are modelled explicitly and are then interacting directly with sensors, actors and functional elements of the building automation and control system (BACS) or are triggering user interaction. By this approach, model configuration and parametrization from the design stage can seamlessly be used in the BACS configuration[7].

The energy demand for lighting in an evaluation area j of a building zone n can directly be derived by:

$$Q_{l,n,j} = \sum_{i=1}^{I} Q_{l,n,i,j} \tag{B.1}$$

from the luminaire or luminaire groups actors ("Light actuator") physical output L (see B.5.2) to the areas by:

$$Q_{l,n,j,i} = p_{j,\max} A_j L_{j,i}, t_{j,i} \tag{B.2}$$

where

I	number of discrete time intervals with constant $L_{j,i}$
i	index of discrete time interval with constant $L_{j,i}$
$L_{j,i}$	lighting actor's physical output, directly controlling fixtures/group of fixtures, values [0,1], rf to B.5.2.
$p_{j,\max}$	fixed or time dependent specific available maximum electrical evaluation power of luminaires in area A_j;

NOTE Currently, ISO/CIE 20086 only provides constant values, i.e. p_j = const. p_j can come from other sources than ISO/CIE 20086 like a detailed lighting design calculation or can refer to a future adapted ISO/CIE 20086, allowing for instance time variant maintained illuminances with therefore corresponding variable p_j.

This general Formula is parametrized in this annex to a practically applicable approach, which is consistent to the building segmentation procedure of A.2. Nevertheless, it also allows free segmentations and flexible time basis and hereby generally is open to more refined approaches.

The method involves the following stages to determine – according to 5.6 – the impact of daylight on the energy demand for electric lighting.

— B.2 contains a reformulation of Formula (2) to an hourly (sub-hour) time basis and a procedure for building segmentation following A.2 and control point allocation. It also outlines the link to the calculation of the specific installed power of the electric lighting system (e.g. see ISO/CIE 20086).

— B.3 specifies and parametrizes an algebraic calculation procedure for the daylight supply and as a come along also a procedure for solar transmission.

— B.4 specifies a user model covering occupancy patterns, lighting requirements and manual interaction with the lighting and solar-/glare protection system.

— B.5 specifies with focus on daylighting selected lighting control elements as part of building automation and control Systems (BACS).

— B.6 holds an example.

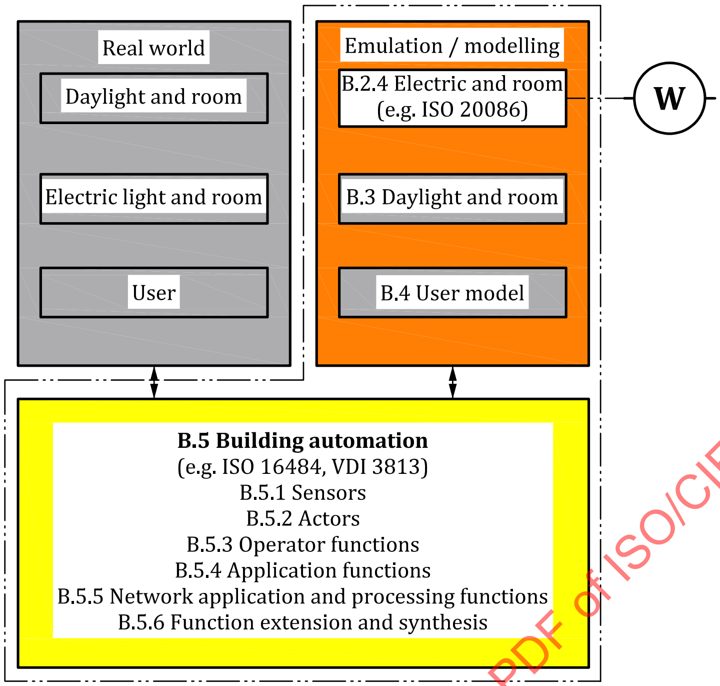


Figure B.1 — Emulation concept and structure of comprehensive hourly method

This document has data sets that are publicly accessible online via ISO at[8] holding parametrizations for the algebraic daylight calculation procedure and user model. B.6 holds an example of how to apply the method.

B.2 Time Basis, Building Segmentation, Control Point Allocation, Link to electric lighting

B.2.1 Time Basis

The time basis generally can be set free as in Formula (B.2). In the scope of the method in this Annex, the following specifications apply. An hourly time basis t_i is assumed, following the main driving data available in building practice, i.e. hourly weather datasets. A subdivision of the hourly time basis:

$$t_i = t_{i,\mathrm{SNA}} + t_{i,\mathrm{SA}} \tag{B.3}$$

into two intervals with sunshading activated “SA” and not activated “SNA” is introduced. This follows facade activation being the main discriminator of lighting supply in daylit buildings (see B.3.2). Activation of sunshading/glare protection depends on the setpoints of for instance the automatic solar controller (see B.5.4), which evaluates radiation or illuminance levels on the facade. This is generally strongly dependent on the dynamics of the used sky model being a function of sunshine probabilities (see B.3.2).

B.2.2 Building Segmentation

Evaluation areas can be subdivided following.

a) The building segmentation according to A.2

$$Q_{l,n,j,i} = p_j \left[A_\mathrm{D} \left(L_{\mathrm{D},j,i,\mathrm{SNA}} t_{i,\mathrm{SNA}} + L_{\mathrm{D},j,i,\mathrm{SA}} t_{i,\mathrm{SA}} \right) + A_\mathrm{ND} L_{\mathrm{ND},j,i}\, t_i \right] \tag{B.4}$$

with $A_j = A_D + A_{ND}$

This can deviate from the real physical segmentation of lighting circuits (and control areas), but can be a good early estimate, when the exact electric circuit segmentation is not yet known[1].

b) The use of other evaluation areas A_j in Formula (B.2), e.g. following the spatial detection range of daylight or occupancy sensors, is possible. This then results in free definition of sensor areas A_j in Formula (B.2) and has to be matched to the systematic of the daylight calculation in B.3.

B.2.3 Control point Allocation

Control points have to be allocated for the electric lighting system (occupancy detection and daylight) and the sun shading/glare control system. This encompasses automatic, i.e. sensors, and manual control, i.e. switches (see B.5.3). This can be matched following the simplified building segmentation as of B.2.2 or can be performed freely following real sensor placement. For real sensor placement, the actual detection area of the sensors defines the areal segmentation into A_j.

a) Electric lighting system

For automatic controls and manual switching of the electric lighting system the following applies.

i) For building segmentation according to A.2: For this option the mean value of V according to A.3.1 has to be assumed. In the case of a vertical facade, the V matrix must have been determined on the basis of the mean value of V matrices on the axis running parallel to the respective facade section and at a distance of half the space depth from the facade. The specifications of V matrices in B.3.4 and B.3.5 do address this. In the case of a rooflight situations a mean illumination over the areas lit by daylight is assumed following A.4. Therefore sensors, reading $E_{\text{Room,day}}(t_n)$ according to B.3.1.1 can be positioned freely over this area.

ii) For real sensor placement: For modelling the behaviour of a real sensor the V Matrix (B.3) has to match the sensor position/detection point or area (then representing an average V).

b) Sun shading

The placement of "brightness and/or irradiance sensors outside" (see B.5.1) for automatic sun shading control shall be assumed on the outside facade in the middle of the window/ facade element of the evaluation area under consideration. On roofs the sensor should be placed unobstructed and horizontally. The sensor positions have to coincide with the point for the OE-Matrix calculations (see B.3.2.2). For manual switching, following the model in B.4.3, in addition the solar penetration at the working plane shall also be considered.

For free modelling, any other control points can be assumed under the constraint of matched matrices OE (outside on the facade) and matrices V (inside the spaces). Luminance based controls in spaces may be employed by relying $V_{v,L}$ indoor luminance matrices (see B.3.1.1).

B.2.4 Link to electric lighting

$p_j(t_i)$ can be obtained from ISO/CIE 20086 (calculated or directly measured) or by an acknowledged lighting design process. Especially $p_j(t_i)$ can – based on the chosen time basis – be made time dependent. By this the variability of the power consumption seen in state of the art SSL (SSL) lighting fixtures as function e.g. of selected colour temperatures ("tunable white") or non-linearities of dimming curves can be regarded. Specification of these functional dependencies are not part of this standard but can be included in the calculation procedure by reference to external functions or tabulated values.

1) The segmentation according to A.2 has proven to work well in different worldwide software implementations of this method (standard). This applies for vertical facades and rooflights.

B.3 Daylight supply and come along solar gain calculation

B.3.1 Algebraic calculation of daylight supply (“3 Phase Method”)

B.3.1.1 Algebraic calculation of photometric quantities: $E_{\mathrm{Room,Day}}(t_n)$, $L_{\mathrm{Room,Day}}(t_n)$

The daylight contribution at the control point(s) in the room is calculated by a light flux transfer calculation broken into the following three phases (“3-Phase-Method”).

— 1st phase: Modelling the light flux from the sky to the exterior of the fenestration unit/rooflight.

— 2nd phase: Modelling the flux transmission through the fenestration unit/rooflight with and without shading.

— 3rd phase: Modelling the light flux from the interior of the fenestration unit/rooflight to the control point(s) in the respective evaluation area.

Figure B.2 provides a systematic overview.

a) Indoor illuminance for general vertical facades, inclined fenestration systems, and rooflights

Indoor illuminance for general vertical facades, inclined fenestration systems, and rooflights is determined by

$$E_{\mathrm{Room,\,Day}}\,(t_i\,) = V_{\mathrm{v,E}}\; T\;\mathrm{OE}\; s_{\mathrm{v}}\,(t_i\,) \qquad \text{(B.5)}$$

where

$E_{\mathrm{Room,Day}}(ti)$	is the n-dim illuminance by daylight vector at the control (reference) points.
$s_{\mathrm{v}}(t_i)$	k-dim vector of fluxes from sky patch luminances of the hemisphere above the building for a given time.
OE	is the outside environment $l \cdot k$ matrix containing the coefficients between incident luminous flux from the k sky patches and the outer environment as seen by the facade on l patches.
T_{v}	is the $m \cdot l$ visual Bidirectional Scattering Distribution Function (BSDF) matrix of the fenestration unit. The visual BSDF describes the light scattering properties of a material (here a facade system, e.g. fenestration with or without glare protection or sunshading) by specifying the amount of light from an incident direction that is reflected and/or transmitted in an exiting direction. BSDFs can be represented as analytical formulae or – as used here – based on tabulated data for given angular supports, i.e. as a $m \cdot l$ matrix of values for l incident and m exiting directions (patches). For sunshading not activated it shall be indexed SNA, i.e. $T_{\mathrm{v,SNA}}$, for sunshading activated $T_{\mathrm{v,SA}}$.
$V_{\mathrm{v,E}}$	is the view point connection $n \cdot m$ matrix connecting the m emitting directions on the inside of the facade with the illuminance at the n sensor points in the considered area.

For more than one vertical facade, inclined fenestration system, and rooflights contributing light to a control/sensor point the illuminance levels according to B.5 are to be superimposed.

b) Indoor luminance for general vertical facades, inclined fenestration systems, and rooflights

For certain controls rather the luminance L[2)] is relevant, which can be derived with

$$L_{\text{Room, Day}}(t_i) = V_{\text{v,L}}\, T\, \text{OE}\, s_{\text{v}}(t_i) \tag{B.6}$$

where $V_{\text{v,L}}$ is the view point connection $n \cdot m$ matrix connecting the m emitting directions on the inside of the facade with the luminance at with the k sensor points in the considered area.

For more than one vertical facade, inclined fenestration system, and rooflights contributing light to a control/sensor point the luminance levels according to B.6 are to be superimposed.

c) Indoor illuminance for rooflights with diffuse glazing/sunshading

For the case of diffuse transmitting rooflights (as for A.4) the hourly calculation can be performed based the daylight factor according to Formula (A.18) following

$$E_{\text{Room, Day}}(t_i) = \bar{D}_j\, I\, \text{OE}_{\text{horizontal,unobstructed}}\, s_v(t_i) \tag{B.7}$$

The $\text{OE}_{\text{horizontal,unobstructed}}$ matrix shall be determined for horizontal incline and without shading. $E_{\text{Room,day}}(t_i)$ gives the average value of the illuminance in the considered evaluation area. For other than diffuse glazing the full V-Matrix based calculation according to (B.5) has to be performed.

For more than one rooflight with diffuse glazing/sunshading contributing light to a control/sensor point the illuminance levels according to Formula B.7 are to be superimposed.

d) Outside illuminance

For the control of facade systems the outside illuminance can be obtained by:

$$E_{\text{Facade, Day}}(t_i) = I\, \text{OE}\, s_{\text{v}}(t_i) \tag{B.8}$$

where I is an all one l-dim vector.

This document comes with numerous example matrices (see B.3.5).

2) For use of luminances in certain lighting control schemes the angular resolution is of crucial importance. A discussion can be found in [9].

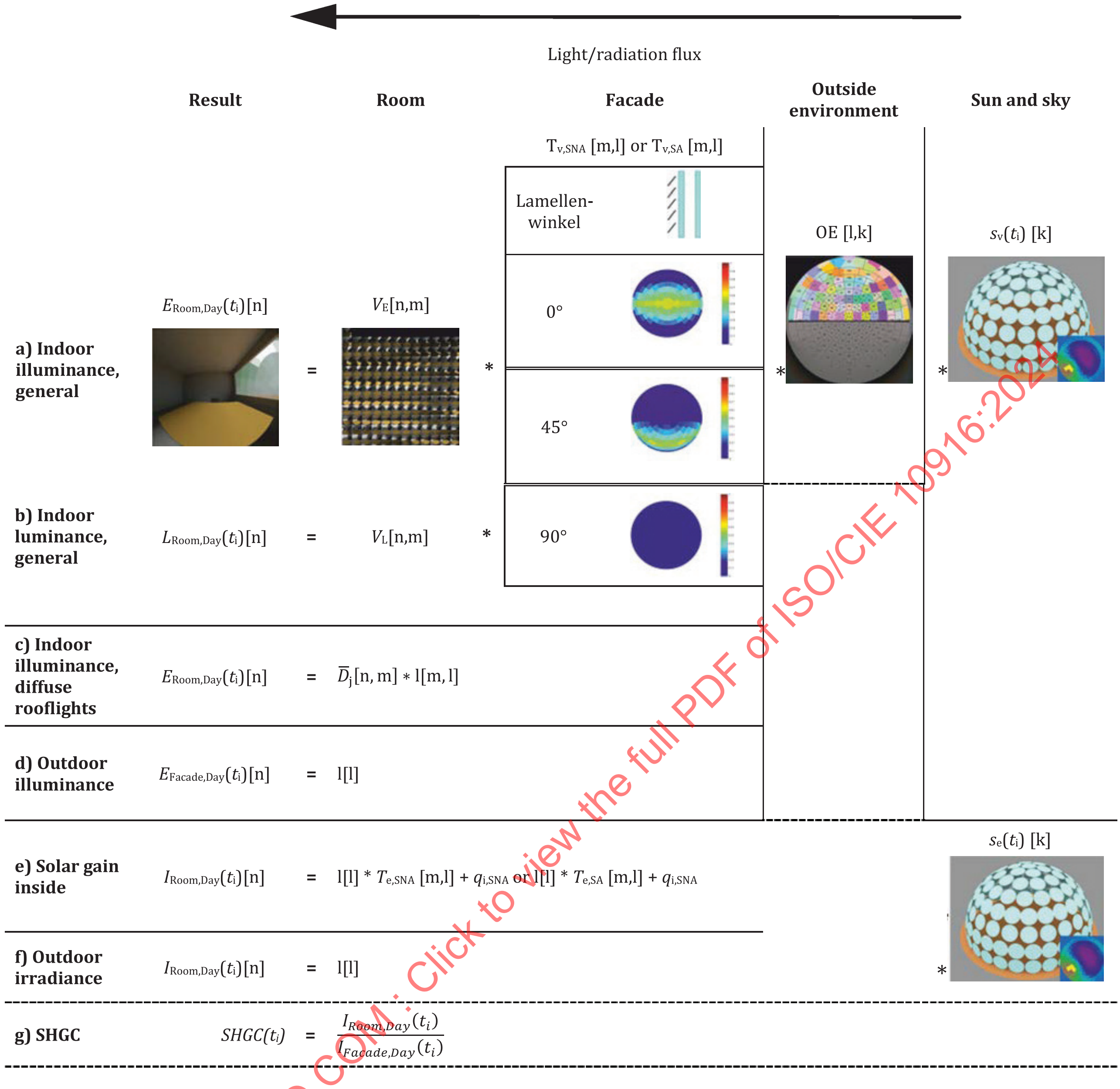
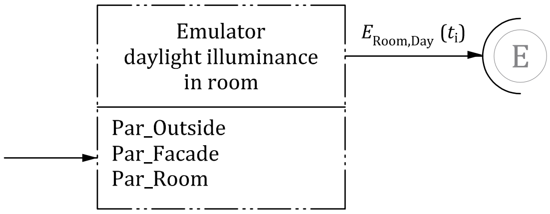
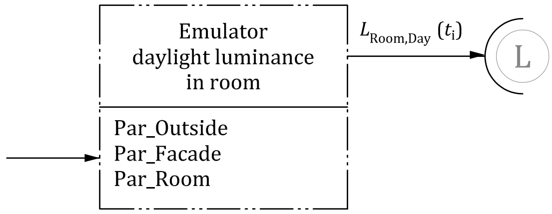


Figure B.2 — Systematic overview of algebraic calculation of daylight and irradiance supply based on the flux transfer method

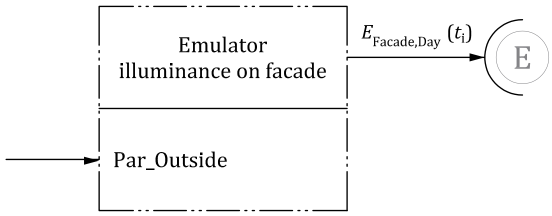
Figure B.3 holds graphical representations following the emulation concept as introduced in B.1, see Figure B.1. The data structures Par_Outside, Par_Facade, Par_Room specify the emulations and can be parametrized following the parameter set in chapter B.3.5.



a) Representation of Formulae (B.5), (B.7)



b) Representation of Formula (B.6)



c) Representation of Formula (B.8)

Figure B.3 — Graphical representation of emulators for lighting as input to sensors in 0.

B.3.1.2 Algebraic calculation of solar gains inside and exterior on facade

Conformity between the physical light and solar radiation flux modelling shall be assured.

a) Indoor irradiance for general vertical facades, inclined fenestration systems, and rooflights.

The transmitted irradiance for general vertical facades and rooflights is described by

$$E_{\text{e,Room,Day}}(t_i) = I\,T_e OE\, s_e(t_i) + q_i(t_i) \tag{B.9}$$

where

$E_{\text{e,Room,Day}}(t_i)$	is the n-dim irradiance vector at the control (reference) points.
$s_{\text{e}}(t_i)$	k-dim vector of fluxes from sky patch radiances of the hemisphere above the building for a given time.
T_{e}	is the $m \cdot l$ optical BSDF matrix of the fenestration unit. The BSDF describes the scattering properties of a material (here a facade system, e.g. fenestration with or without glare protection or sunshading) by specifying the amount of radiation from an incident direction that is reflected and/or transmitted in an exiting direction. BSDFs can be represented as analytical formulae or – as used here – based on tabulated data for given angular supports, i.e. as a $m \cdot l$ matrix of values for l incident and m exiting directions (patches). For sunshading not activated it can be indexed SNA, i.e. $T_{\text{e,SNA}}$, for sunshading activated $T_{\text{e,SA}}$.
$q_i(t_i)$	the convective part q_i, i.e. the thermal heat transfer through the fenestration unit.

For example, data for angular dependent BSDF, see B.3.5. q_i can be determined following[10].

b) Outside irradiance.

For the control of facade systems, the outside irradiance can be obtained by:

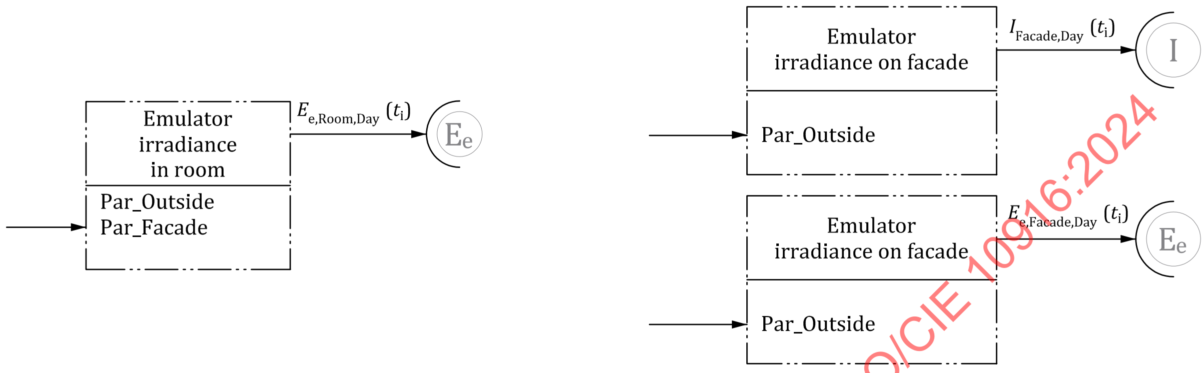
$$E_{\text{e,Facade,Day}}(t_i) = I\,\text{OE}\, s_{\text{e}}(t_i) \tag{B.10}$$

c) Solar heat gain coefficient (SHGC).

The angular dependent solar heat gain coefficient $\mathrm{SHGC}(t_i)$ can be obtained by

$$\mathrm{SHGC}(t_i) = \frac{E_{\mathrm{e,Room,Day}}(t_i)}{E_{\mathrm{e,Facade,Day}}(t_i)} \tag{B.11}$$

Figure B.4 holds graphical representations following the emulation concept as introduced in B.1, see Figure B.1. The data structures Par_Outside, Par_Facade, Par_Room specify the emulations and can be parametrized following the parameter set in chapter B.3.5.



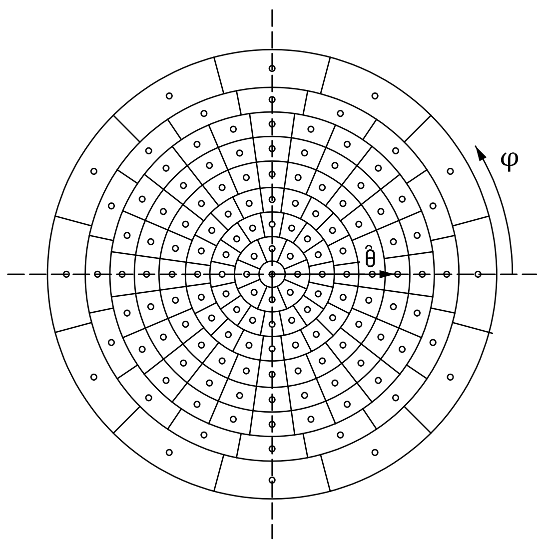
a) Representation of Formula (B.9) **b) Representation of Formula (B.10)**

Figure B.4 — Graphical representation of emulator for irradiance as input to sensors in 0.

B.3.1.3 Angular basis (Data resolution)

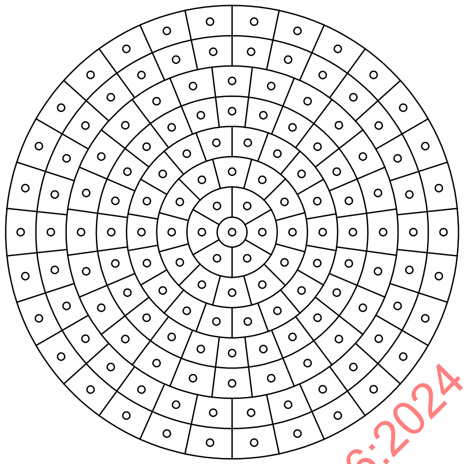
The angular basis determines the resolution and accuracy of the algebraic calculation of daylight supply (the "3 Phase method"). It generally is built around the basis of the T_v (T_e) matrices, i.e. the data resolution of the BSDF of the fenestration unit. For energy calculation purposes two angular basis schemes, the "Klems" and "Tregenza" scheme are practically established[9,12,11]. Measurement facilities and calculation schemes are generally following these conventions[9]. Figure B.5 specifies both schemes of angular discretization into altitude and azimuth angle pairs [θ, φ] of the incident and exiting hemispheres. Other (higher) resolutions can be used accordingly, if corresponding data are available.

Number of incident directions	
145	
Incident/exiting directions	
θ [°]	φ [°]
0	0°
10	0° to 315°, 45° increments
20	0° to 337,5°, 22,5° increments
30	0° to 342°, 18° increments
40	0° to 345°, 15° increments
50	0° to 345°, 15° increments
60	0° to 345°, 15° increments
70	0° to 337,5°, 22,5° increments
82,5	0° to 330°, 30° increments



a) Klems[9,11]

Number of incident directions	
145	
Incident/exiting directions	
θ [°]	φ [°]
0	0°
12	0° to 300°, 60° increments
24	0° to 330°, 30° increments
36	0° to 340°, 20° increments
48	0° to 345°, 15° increments
60	0° to 345°, 15° increments
72	0° to 348°, 12° increments
84	0° to 348°, 12° increments



b) Tregenza[11,12]

Figure B.5 — Two BSDF angular basis

B.3.2 Requirements for climate data, i.e. sky vector $s_v(n)$ and outside environment (OE)

B.3.2.1 Sky vector $s_v(n)$

According to the selected angular basis sky vectors $s_v(t_i)$ ($s_e(t_i)$) are to be calculated as function of astronomic and local climate. As within an hourly interval the biggest dynamics between real sky conditions are generally between sunshine and no sunshine, the dynamic is assumed to be a function of the sunshine probability. For the two intervals t_{SSP} and $t_{1\text{-}SSP}$ separate sky vectors $s_{v,SSP}(t_i)$ and $s_{v,1\text{-}SSP}(t_i)$ ($s_{e,SSP}(t_i)$ and $s_{e,1\text{-}SSP}(t_i)$) shall be considered.

The relative luminance distributions of two parametrizations of the CIE standard general sky[13,14], the overcast sky: type 16 and the standard clear sky, some pollution: type 13, and direct insolation are scaled by data derived from the diffuse and direct (normal) insolation contained in standard weather data files.

The luminances for different sky conditions are then superimposed following a mean sky concept as described in[20],[21] weighing overcast and clear sky conditions as function of the sunshine probability.

For time interval $t_{1\text{-}SSP}$:

$$s_{v,1-SSP}(t_i)(\theta,\varphi) = (1-SSP)\frac{E_{oc\_measured}}{E_{CIE\_Type16}} L_{CIE\_Type16}(t_i)(\theta,\varphi) + SSP\frac{E_{cl\_measured}}{E_{CIE,Type13}} L_{CIE\_Type13}(t_i)(\theta,\varphi) \quad \text{(B.12)}$$

For time interval t_{SSP}:

$$s_{v,ssp}(t_i)(\theta,\varphi) = (1-\mathrm{SSP})\frac{E_{oc\_measured}}{E_{CIE\_Type16}} L_{CIE\_Type16}(t_i)(\theta,\varphi) + \mathrm{SSP}\frac{E_{cl\_measured}}{E_{CIE\_Type13}} L_{CIE\_Type13}(t_i)(\theta,\varphi) + L_{direct\_sun}(t_i)(\theta,\varphi) \quad \text{(B.13)}$$

with

$$L_{direct\_sun}(t_i)(\theta_{sun},\varphi_{sun}) = \frac{E_{direct\_sun,measured}}{\Omega(\theta_{sun},\varphi_{sun})}\cos(\theta_{sun})$$

where

θ, φ	are angle of sky patch according to Klems or Tregenza scheme;
L_{CIE_Type16}	is the luminance of the CIE standard general sky, type 16, traditional CIE overcast sky [cd/m^2];
L_{CIE_Type13}	is the luminance of CIE standard general sky, type 13, standard clear sky [cd/m^2];
L_{direct_sun}	is the luminance of the associated sun patch of direct insolation;
E_{CIE_Type16}	is horizontal illuminance of the CIE standard general sky, type 16, traditional CIE overcast sky [lx];
E_{CIE_Type13}	is horizontal illuminance of CIE standard general sky, type 13, standard clear sky [lx];
$E_{oc\_measured}$	is horizontal illuminance for overcast sky conditions from weather data files [lx];
$E_{cl\_measured}$	is horizontal illuminance for clear sky conditions from weather data files [lx];
$E_{direct\_sun\_measure}$	is horizontal illuminance by direct sun light from weather data files [lx];
SSP	is sunshine probability from weather data files;
$\theta_{sun}, \varphi_{sun}$	are angle of sun patch according to Klems or Tregenza schemes;
Ω	is solid angle of sun patch according to Klems or Tregenza schemes.

The required parameters horizontal illuminance for overcast $E_{oc\_measured}$, clear sky conditions $E_{cl\_measured}$ and by direct sunlight $E_{direct\_sun\_measured}$ and SSP are available as data sets (see B.3.5) for the selected different locations and climates according to A.3.2.2 (Table A.2).

Comparable other dynamic sky models or real data (sky scanner) can be used alternatively. For appropriate facade action, these should allow to break down hourly intervals into subintervals with and without direct insolation.

B.3.2.2 Outside environment (OE)

The outside environment $l \cdot k$ matrix OE describes the relation between incident luminous flux from the k sky patches and the outer environment as seen by the facade on m patches. It therefore holds the impact of reflections by the ground, shading of light by obstructions of the facade, as well as of interreflections between the building containing the room to be evaluated itself and outside obstructions of the facade. For example OE matrix data sets refer to chapter B.3.5.

B.3.3 Requirements for T_v, T_e, i.e. BSDF data

BSDF data for T_v and T_e from multiple sources can be used. For standard transparent or strongly diffuse transmitting integrated glazing units (IGUs) they can be determined analytically (e.g. Fresnel equations, Lambert diffusor model). For other integrated glazing units (IGU), e.g. with static light redirecting elements, or IGUs in combination with dynamic sunshading or glare protection units either measured or numerically determined BSDF data shall be used. The integrated units can be measured or numerically determined as a whole or can be numerically combined via algebraic calculation[10,11] from single components to IGUs[10,11,15]. The angular basis of the data have to follow the specifications of B.3.1.3.

The measurement based or numerical (e.g. via forward raytracing algorithms) goniophotometric assessment procedure has to be quality assured[9,12]. BSDF datasets for lighting (T_v) and solar gains (T_e) calculation ideally should be determined in the same measurement device or with the same numerical procedure.3)

For dynamic systems, like venetian blinds, different datasets for the different incline angles of lamellas may be used. This incline angular scheme has to match the control schemes (e.g. cut-off compare to B.5.4, here “Slat Tracking”).

Subclause B.3.5 holds a selection of typical IGUs combined with typical sunshading and glare protection systems.

B.3.4 Requirements for view point connection matrix

View point connection matrices $V_{v,E}$ and $V_{v,L}$ can be determined for specific spaces, specific facade configurations, i.e. positioning of daylight openings, and reference or control points. Their determination has to take into account the relevant boundary conditions, i.e. space geometry and material properties (e.g. surface reflectance). Different lighting simulation programs nowadays offer this calculation process. Subclause B.3.5 holds a selection of view point connection matrices for typical room configurations.

B.3.5 Parametrization of typical daylight scenarios

For the two given angular basis schemes, “Klems” and “Tregenza” following B.3.1.3 the data sets provided via an ISO server[8] contain exemplarily parametrizations for typical daylight scenarios which parametrize Formulae (B.5), (B.6), (B.7), (B.8), (B.9), (B.10). Table B.1 gives an overview of the data files.

Table B.1 — Data files accessible via ISO for parametrization of typical daylight scenarios[8]

#	Filename	Description
1	ISO_10916_Weatherdata.xml	Illuminances and sunshine probabilities for the locations according to Table A.2, derived from TRY weather data sets.
2	ISO_10916_Matrices_OE.xml	Coefficients OE between incident luminous flux from the sky patches and the outer environment as seen by the facade for typical outside shading scenarios.
3	ISO_10916_Matrices_Tv_Te.xml	T_v and T_e (BSDF) of integrated glazing units with and without sun-shading/glare protection.
4	ISO_10916_Matrices_Vv_h_wwr_rfl_rw_rc.xml	View point connection matrices $V_{v,E}$. Parametrization of specific files according to Table B.4. The file naming convention is h: room height, wwr: window wall ratio, rfl: ρ_{Floor}, rw: ρ_{Walls}, rc: $\rho_{Ceiling}$. The files each contain the variation of the room width and room depth.

Formally, the parameter structures Par_Outside, Par_Facade and Par_Room following the graphical representation of the emulator according to B.3.1. parametrize the daylight scenarios of the data files specified in Table B.2.

3) For spectrally neutral (“grey”), i.e. generally independent of wavelength, components of shading devices the same BSDF may be taken. This nevertheless does not hold true for the combination with todays coated glazing components, which spectrally highly selective. These can numerically be combined for instance in WINDOW 7.

Table B.2 — Parameter structures for parametrization of typical daylight scenarios for data files on ISO server

#	Structure Name	Parameter
1	Par_Outside	Site
		Albedo [%]
		Linear_Shading_Angle [°]
2	Par_Facade	Albedo [%]
		Glazing_Type [-]
		Sunshading_Type [-]
		Sunshading_Position [-]
3	Par_Room	Width [m]
		Depth [m]
		Height [m]
		Window_Wall_Ratio [%]
		Reflection_Coefficients (ρ_{Floor}, ρ_{Walls}, $\rho_{Ceiling}$) [%,%,%]

— Illuminances and sunshine probabilities for selected locations

The file *ISO_10916_Weather.xml* contains illuminances and sunshine probabilities on an hourly basis according to the locations listed in Table A.2 for parametrizing the sky vector $s_v(n)$ according to B.3.2.1.

— Outer environment (OE)

The file *ISO_10916_Matrices_OE.xml* holds coefficients between incident luminous flux from the sky patches and the outer environment as seen by vertical facades for linear shading of 0°, 15°, 30°, 45° for outside reflections (Albedo) of 10 %, 20 %, 30 %, 40 %. A set of coefficients for unobstructed horizontal facades is provided as well.

— Glazing and sunshading T_v and T_e

The file *ISO_10916_Matrices_Tv_Te.xml* holds T_v and T_e (BSDF) datasets of integrated glazing units (IGUs) without and with sunshading/glare protection. The datasets are provided for the five IGUs in Table B.3 alone and each in combination with the sunshading and glare protection systems. As combined sunshading and glare protection systems a venetian blind system with opaque grey 0,08 m wide slats with a ratio of slat width to distance between slats of 0,072 m; diffuse reflection of slats: 80 %, slat angles varying in 10° steps (from closed to fully open) and a textile blind system (grey, densely woven with a direct hemispherical light transmission of 5 %) are provided. Their position is varied between inside, in the gap of the panes, and outside of the IGU, see Figure B.6.

Table B.3 — Data of typical low ε glazing, solar glazing (double and triple)

#	Glazing_Type	$\tau_{v,D65}$	τ_e [a]	*Ra*	*g*-Value	Selectivity *S*	U_g
		[%]	[%]	[-]	[-]	[-]	[W·m^{-2}·K^{-1}]
1	Low ε glazing, double	82	57	98	0,65	1,26	1,1
2	Low ε glazing, triple	74	45	96	0,53	1,4	0,7
3	Moderate Solar glazing, triple	66	34	94	0,39	1,69	0,7
4	Stronger Solar glazing, triple	46	21	91	0,25	1,84	0,7

[a] Calculated for wavelength: 300 nm to 2 500 nm following definition in EN 410[22]

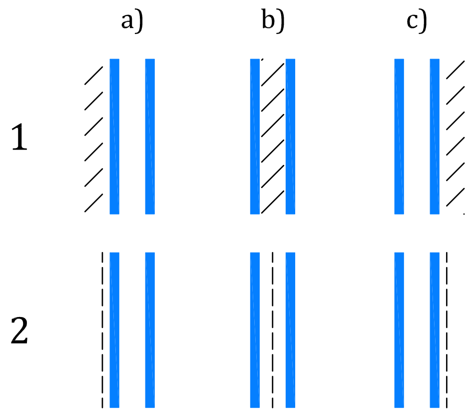


Figure B.6 — Sunshading type (glare protection type) and position: Venetian blinds and textile in relation to the panes of a two pane IGU.

For typical rooflight systems, generally, the diffuse light transmission can be assumed (see (B.7)). For diffuse light transmission, the luminance coefficients in matrix T_v can be assumed constant. A normalized T_v matrix is provided in the file. The IGUs according to Table B.3 can be employed for rooflights use as well.

Table B.4 — Data of typical rooflight components

#	Polycarbonate sheets	$\tau_{v,D65}$	τ_e [a]	*Ra*	*g*-Value	Selectivity *S*	U_g
		[%]	[%]	[-]	[-]	[-]	[W·m^{-2}·K^{-1}]
1	5-layers, 20 mm, transparent	59	52	100	0,57	1,1	1,7
2	5-layers, 20 mm, diffuse	47	43	99	0,47	1,0	1,7
3	7-layers, 16 mm, clear	55	51	99	0,53	1,0	1,7
4	7-layers, 16 mm, diffuse	38	33	96	0,38	1,0	1,7

[a] Calculated for wavelength: 300 nm to 2 500 nm.

— View point connection matrices V

The file ISO_10916_Matrices_Vv_h_wwr_rfl_rw_rc.xml holds view point connection matrices $V_{v,E}$ for each of the parameter combinations according to Table B.5 for vertical facades. These cover different room dimensions, window wall ratios and reflection coefficients. Values are provided for different reference/control points.

— Following the control point allocation, as described in B.2.3, referring to the building segmentation procedure according to A.3.1.

— For more specific positioning of sensors and following spatial daylight autonomy concepts, values are provided on standardized grids over the area benefitting from daylight.

For the later grid cells, approximating to a square is preferred. The ratio of length to width of a grid cell shall be kept between 0,5 and 2. The maximum grid size shall be:

$$p = 0{,}5 \times 5^{\log_{10}(d)} \qquad \text{(B.14)}$$

where

$p \leq 10$ m,

d is the longer dimension of the calculation area (m), however if the ratio of the longer to the shorter side is 2 or more then d becomes the shorter dimension of the area, and

p is the maximum grid cell size (m).

The number of points in the relevant dimension is given by the nearest whole number that is equal to or greater than d/p.

The resulting spacing between the grid points is used to calculate the nearest whole number of grid points in the other dimension. This will give a ratio of length to width of a grid cell close to 1.

In addition, values in the geometric centre of the rooms are provided.

At each reference point the horizontal illuminance is determined at a height above floor of 0,85 m and the vertical illuminances in the four directions perpendicular and parallel at a height above floor of 1,2 m (eyeheight of a seated observer). The placement of windows in the vertical walls (facade) is specified in the corresponding VMX files. Window sizing and positioning as function of the Window_Wall_Ratio will be provided in the technical report. Windows are horizontally centred in the walls.

Table B.5 — Room parameters Par_Room for which $V_{v,E}$ matrices in ISO_10916_Matrices_v.csv are provided

#	Parameter	Parameter setting
1	Width	2 m; 3 m; 4 m; 5 m; 6 m; 7 m; 8 m; 9 m; 10 m
2	Depth	3 m; 4 m; 5 m; 6 m; 7 m; 8 m
3	Height	2,5 m; 3 m; 3,5 m; 4 m
4	Window Wall Ratio	25 %; 40 %; 60 %; 100 % (description of window placement: balustrade and lintel for 25 %; 40 %; 60 %: ...)
5	Reflection coefficients (ρ_{Floor}, ρ_{Walls}, $\rho_{Ceiling}$)	"Dark": 10 %, 30 %, 30 %
		"Standard": 20 %, 50 %, 70 %
		"Standard": 20 %, 50 %, 70 %

B.4 User Model: Occupancy, lighting requirements and system interaction

B.4.1 General

User's influence on the lighting energy demand depends on their presence in the evaluation area/space (occupancy), their lighting requirements and their interaction with the electric lighting system and the daylight system (i.e. sun/glare protection).

B.4.2 Occupancy patterns

Occupancy patterns represent presence of individuals or group of individuals in an evaluation area in the considered time interval. The occupancy signal can be assigned as input to:

— automated systems, i.e. occupancy sensors;

— as masking/windowing function for the time interval in which occupants can manually interact with the lighting and shading system (ref. to B.4.4).

Occupancy spatially can be assigned to an evaluation area or also to individual workplaces. Individual control points/areas have to be specified. Practically these are in accordance with reference points (view matrix) for daylight sensing (B.3), as often integrated daylight and occupancy sensors are employed.

B.4.5 provides a selection of representative hourly schedules. Linkage to stochastic modelling of occupancy is possible as well[16]. Also, especially for judging the impact/influence of subhour effects of occupancy sensing like subhour delays in switching off – requesting then higher sampled user occupancy patterns as for instance to be obtained by[16], sub hour simulations for these effects may be run. In order to be aligned with the hourly by climatic data driven daylight calculations, these then have to aggregated to hourly values,

Figure B.7 holds a graphical representation following the emulation concept as introduced in B.1, see Figure B.1. The data structures Par_User specifies the emulation and can exemplarily be parametrized following B.4.4. Occupancy patterns serve as input *P* to presence detection sensors (see B.5.1) or as masking/windowing function to the manual light switch models/emulators (see B.4.3).

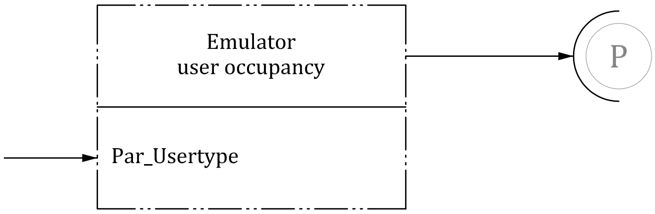


Figure B.7 — Graphical representation of emulator for occupancy as input to sensors in 0.

B.4.3 Lighting requirements for automatic controls

Lighting requirements serve as set values for automatic operation by lighting controls. This applies provided the appropriate and corresponding design of the electric lighting system (e.g. translation into dimming levels, if the lighting system has that max. power/can provide the required output) and also daylighting (e.g. glare protection).

The set values can encompass visual (e.g. E_m, CCT) as well as non-visual parameters (e.g. $E_{v,mel}$ at eye level). These can be specified on an hourly basis. They can be defined as function of age, gender, (individual) glare sensitivity, availability (cost) of electric power, if adequate data are available (rf. also to the concept of so called "context modifiers"[17]). Formally lighting requirements are represented by an application function "Lighting Requirements" as specified in B.5.5 or as direct parameters for application functions like "Daylight Dependent Lighting" as also specified in B.5.5.

Corresponding models to describe electric power demand of the luminaires as function of the dimming state or selected colour temperature are to be assumed (B.2.4 and B.5.2).

B.4.4 Interaction of user with lighting system

Interaction of users with electric lighting and sun/glare protection is either manual or automatic or in in different combinations thereof:

a) both fully manual;

b) electric lighting manual, sun/glare protection automatic;

c) electric lighting automatic sun/glare protection control manual;

d) fully automatic.

For automatic lighting controls the lighting requirements define the set values (see B.4.3). For automatic sunshading activation, often irradiance values (set points) are used.

— Simple manual switching model electric lighting

For electric lighting, the input to a manual on/off light switch L_{Set} (B.5.3 "Manual Light Switch) can be modelled as function of the illuminance at the control point (respectively work area) for the occupation time by:

$$L_{Set} = \begin{cases} 1 \text{ if } E_{Room,Day} < E_{Setpoint} \\ 0 \text{ if } E_{Room,Day} \geq E_{Setpoint} \end{cases} \quad (B.15)$$

with $E_{Setpoint}$ = 150 lx as recommended value[18], depicted in Figure B.8.

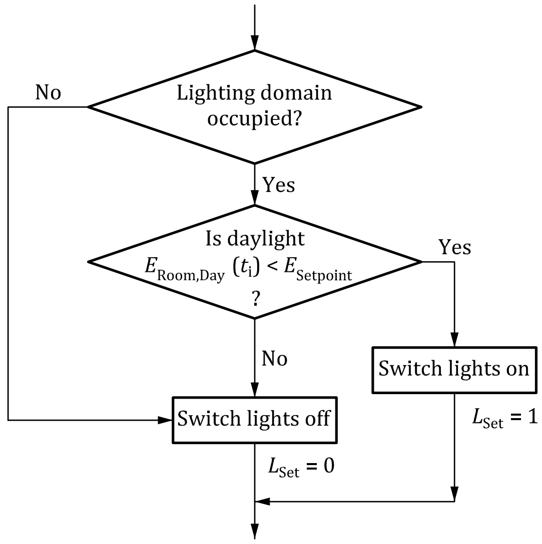


Figure B.8 — Flow chart of model for simple manual switching of electric lighting.

Other models/assumptions e.g. based on vertical illuminances can be used to define L_{Set} as function of manual switching as well. Figure B.9 holds a graphical representation of manual switching as input to a manual light switch (see B.5.3) sending L_{Set} to an actor following the introduced emulation concept in B.1, see Figure B.1.

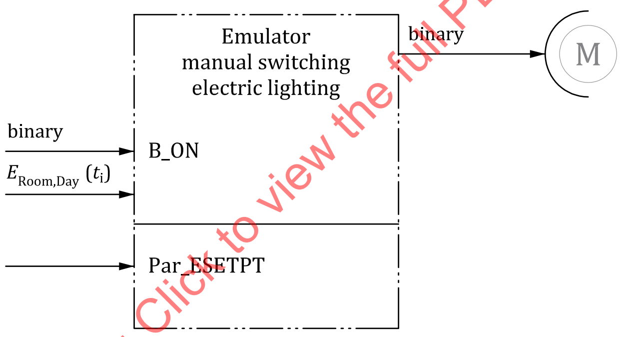


Figure B.9 — Graphical representation of emulator for manual switching of electric lighting as input to operator functions in B.5.3.

— Simple manual sun/glare protection model

Manual operation of sun/glare protection can be modelled such that with occupation of an evaluation area the sun/glare protection is assumed to be open, then as function of the possible solar penetration into the space and irradiance on the facade it will be closed when the condition

$$S_{Set} = \begin{cases} 0 \\ 1 \text{ if } SolarPenetration \neq 1 \text{ and } E_{e,Facade} \geq E_{e,Setpoint} \end{cases} \qquad \text{(B.16)}$$

with a recommended $I_{Setpoint}$ = 233 W/m^2 [18] is fulfilled and will remain in this state until the end of that occupation interval/period.

The variable *SolarPenetration* is 1 if direct sunlight hits the reference point/control point. This signal can be derived either by evaluating the geometric relation of the window and the control point position or by evaluating a threshold illuminance level at the control point. (See Figure B.10)

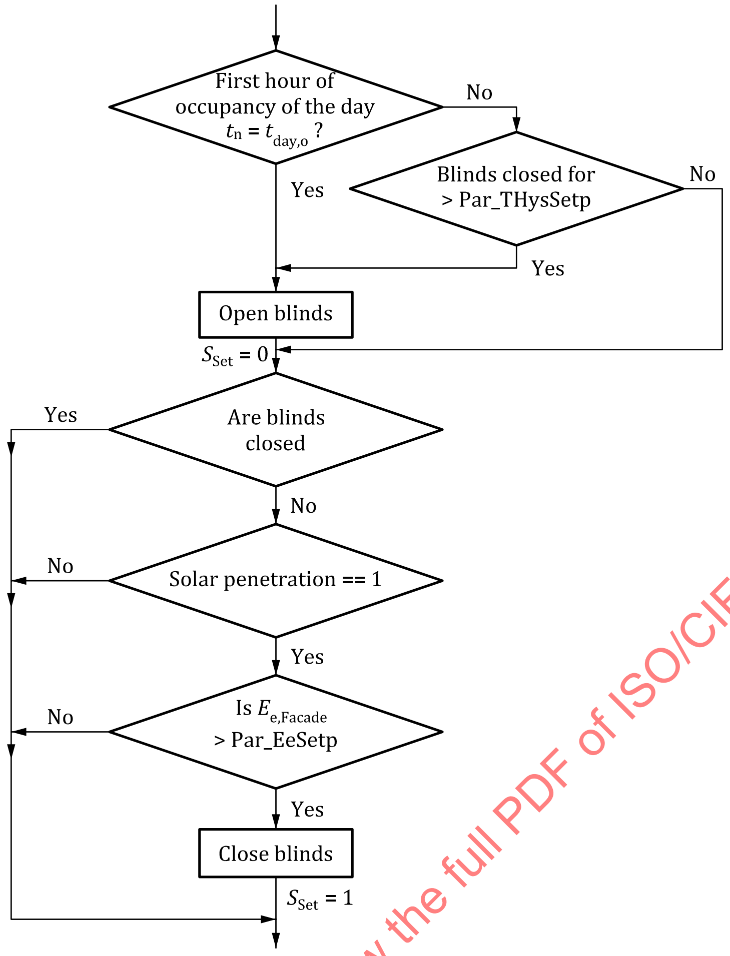


Figure B.10 — Flow chart of a simple model for manual switching sunshading/glare control

Other models/assumptions can be used to define S_{Set} as well. Figure B.11 holds a graphical representation of manual switching as input to a manual shading switch (see B.5.3) sending S_{Set} to an actor following the introduced emulation concept as introduced in B.1, see Figure B.1.

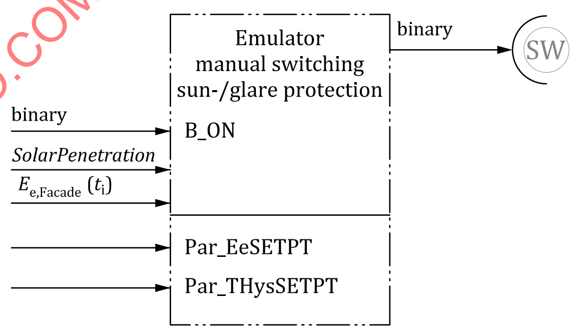


Figure B.11 — Graphical representation of emulator for manual switching of sunshading/glare control as input to operator functions in B.5.3

— Combinations of manual electric lighting switching and sun/glare protection activation

The manual modes can be combined with automatic modes each (refer to 0). In any case sun/glare protection have to be evaluated first to assess the proper daylight supply for the electric lighting to act upon.

B.4.5 Parametrization of typical occupancy patterns and user requirements

Following the specifications in B.4.2 and B.4.3, the ISO server[8] contains exemplarily parametrizations for typical occupancy patterns and lighting requirements scenarios. Table B.7 gives an overview of the data files.

Table B.6 — Data files on ISO server for parametrization of typical user requirements and occupancy patterns (Personas)

#	Filename	Description
1	ISO_10916_OccupancyPatterns.xml	Hourly occupancy patterns for the schedule of interior (areas) following space types as in ISO/CIE 20086
2	ISO_10916_Requirements.xml	Hourly lighting requirements for — The constant illuminance levels E_m of interior (areas) tasks and activities of ISO/CIE 8995-1. — Integrative lighting schemes with over the day-time variable requirements (E_m, CCT,)

Formally, the parameter structures Par_User employed by the occupancy emulator according to B.4.2 and the application function "Lighting Requirement“ in B.5.4 refers to occupation patterns and lighting requirements of the data files specified in Table B.6. The Par_User structure can be extended, if needed.

Table B.7 — User parameters Par_User for parametrizing occupancy and lighting requirements

#	Structure Name	Parameter
1	Par_User	Occupancy_Pattern
		Lighting_Requirements

B.5 Building automation and control systems (BACS): daylighting control elements

B.5.1 General

Sensor, actor, operator, application, and general network function elements definitions follow general building automation and control systems (BACS) specifications as in[7]. Real operational components generally have a bigger set of configuration parameters (PAR_xxx), which are not required in the scope of this energy demand calculation (e.g. only relevant for sub hourly controls like short term hysteresis). For a transition from this design specification into an operational installation the element definitions can then be extended, relying on the here already defined basic structure and parametrization. Symbols and indices follow on the emulation side the naming convention in this document and may be transformed to BACS notations used in the following symbolic, graphical representations with “translation tables”.

The following specification describes essential elements relevant for lighting installations only. The specification nevertheless can be combined with other, e.g. network BACS functions. This can for instance be wind velocity-based protection of external solar shading units to refine the rating of daylight supply as function solar shading activation. In part it relies on functional implementations from other standards (e.g. calculation of sun position).

This document comprises the following set of elements.

— Sensors (B.5.2):

  — Brightness sensor outside,

  — Irradiance sensor outside,

  — Brightness sensor inside,

  - Presence detection.
- Actors (B.5.3):
  - Lighting actuator,
  - Sunshade actuator.
- Operator functions (B.5.4):
  - Manual light switch,
  - Manual blind/shading operation.
- Application functions (B.5.5):
  - Lighting Requirements
  - Daylight Dependent Lighting,
  - Automatic Solar Control,
  - Slat tracking (complex sunshading).
- Selected network application and processing functions (B.5.6):
  - Time signals,
  - Solar altitude calculation,
  - References to additional functions like “automatic thermal control”, “wind speed”.

In addition, a generic scheme to define function extensions is provided (B.5.7).

Sensors, actors, operator functions, application functions, selected network application and processing functions provide and process sensor signals instantaneously at time step *n*.

B.5.2 Sensors

- Brightness and irradiance sensor outside

The “brightness sensor outside” and “irradiance sensor outside”, shown in Figure B.12, read the outside illuminance $E_{\text{Facade,day}}(t_i)$, respectively irradiance $E_{\text{e,Facade,day}}(t_i)$ on a facade according to emulation following Formulae (B.8) and (B.10). Output E_FACADE [lx]/Ee_FACADE [W/m^2] will serve as input to the application function automatic “solar control” (B.5.5)

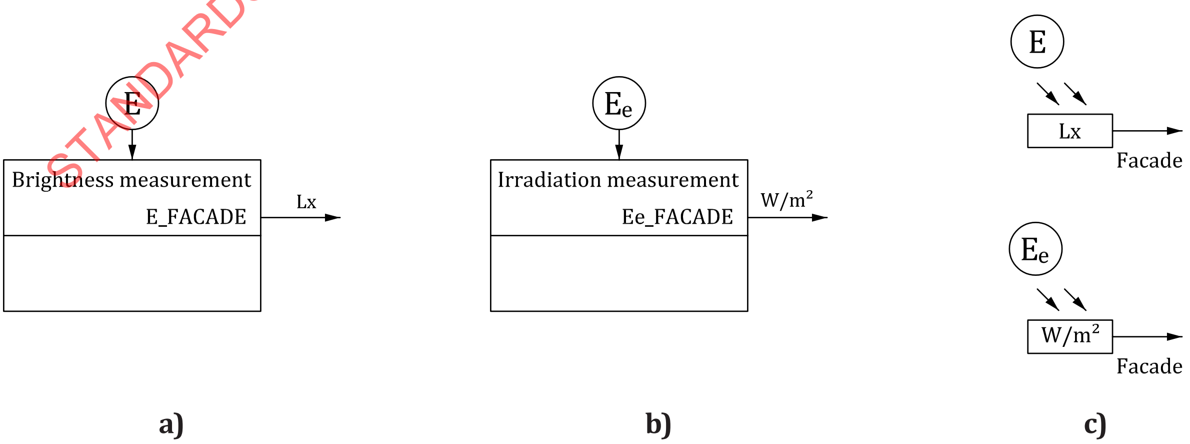


Figure B.12 — SENSOR: “brightness measurement outside”respectively “irradiation measurement outside” on facade and corresponding simple graphic representation

— Brightness sensor inside

The “brightness sensor inside” , shown in Figure B.13, provides the illuminance (respectively irradiation) in a room $E_{\mathrm{Room,day}}(t_{\mathrm{i}})$ according to emulation following Formula (B.5) at the reference/control point. Output E_ROOM in lx will serve as input to the application function “daylight dependent lighting” (B.5.4)).[4)]

a) b)

Figure B.13 — SENSOR: “brightness measurement inside” and corresponding simple graphic representation

— Presence detection

The “presence detection” sensor, shown in Figure B.14, provides the occupancy *P* in a room/area. Output P_AUTO as binary signal [Yes/No] can serve as direct input to the application functions as “daylight dependent lighting”, “automatic solar control” (see B.5.4) (e.g. masking the control of the lighting system, or triggering movement of solar shading) or as input to the application function “Occupancy evaluation”, merging automatic, sensor based presence detection with the operator function “Signal Presence” of a manual light switch in B.5.3.

a) b)

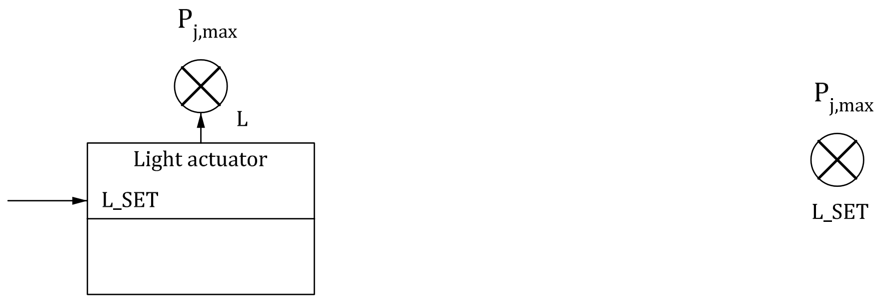
Figure B.14 — SENSOR: “Presence detection” and corresponding simple graphic representation

B.5.3 Actuators

— Lighting Actuator

The "Lighting actuator“, shown in Figure B.15, switches or dims a luminaire or luminaire group according to the provided switching/dimming value L_SET provided by an operator function "Manual Light Switch“ or application function "Daylight Dependent Lighting“. The physical output *L* is directly proportional to the power demand of the luminaire/luminaire group, i.e. $p_j(t_n) = L \cdot p_{j,\mathrm{max}}$ and is used in the balance Formula (B.2).

4) A real indoor brightness sensor detects the illuminance by day- and electric lighting as part of a feedback control loop.



a) b)

Figure B.15 — ACTUATOR: "Light Actuator"

— Sunshade Actuator

The "Sunshade actuator", shown in Figure B16, controls the state S_SET of the shading device. For Instance, in case of a venetian blind system this can be the position and angular tilt, in case of textile blinds just the position. The physical output M is the control state of the motor control relay. Within the data structure S_SET, relative positions (relative to the window/glazed facade height) are assumed and relative angles (relative between 0, e.g. for horizontal slat incline, and 1 for closed blinds).

a) b)

Figure B.16 — ACTUATOR: "Sunshade Actuator"

B.5.4 Operator functions

— Manual Light Switch

The "Manual Light Switch" operator function, shown in Figure B.17, connects the manual switching probability emulation with a light actuator [on/off, no dimming].

a) b)

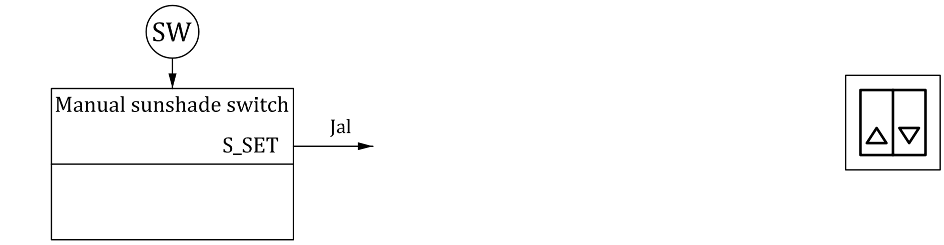
Figure B.17 — Operator function: "Manual Light Switch" in Room

— Manual blind/shading operation

The “Manual blind / shading” operator function, shown in Figure B.18, provide the functionality:

— Up/down

— And tilt angle



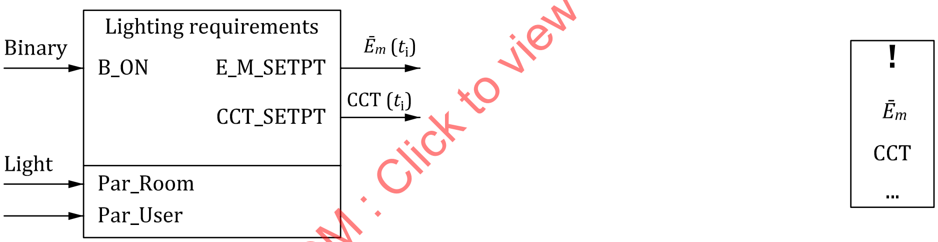
a) b)

Figure B.18 — Operator function: “Manual Blind/shading operation” in Room

B.5.5 Application functions

— Lighting Requirements

The “Lighting Requirement” application function, shown in Figure B.19, processes the PAR_Room, PAR_User with respect to relevant lighting requirements as specified in B.4.2 and the binary “B_ON” signal as from “TIME_Signal” and derives $\bar{E}_\mathrm{m}\,(t_i)$ and CCT (t_i) as dynamic set points for other application functions as e.g. Daylight-dependent-lighting. The application function may be extended to other set point quantities as for instance luminances or contrast ratios.



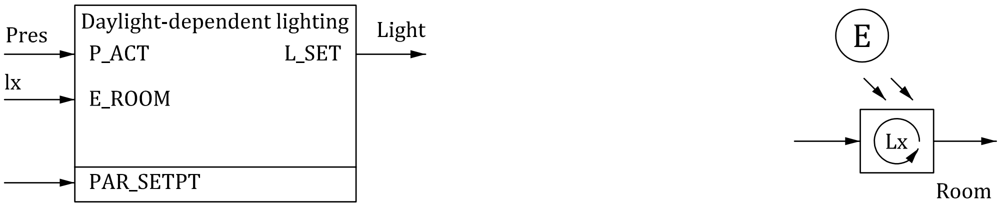
a) b)

Figure B.19 — APPLICATION FUNCTION: “Lighting Requirements”

— Daylight Dependent Lighting

The “Daylight Dependent Lighting” application function, shown in Figure B.20, processes the E_ROOM reading as from Sensor “Brightness Measurement Inside” and derives L_SET from the difference of E_ROOM and PAR_SETPT which represents the maintained illuminance. The function is masked by P_Act.

$$L_{\mathrm{SET}} = \begin{cases} 0 & \text{if E\_ROOM} \geq \text{PAR\_SEPT} \\ \dfrac{\text{PAR\_SEPT} - \text{E\_ROOM}}{\text{PAR\_SEPT}} & \text{if E\_ROOM} < \text{PAR\_SEPT} \end{cases} \tag{B.17}$$



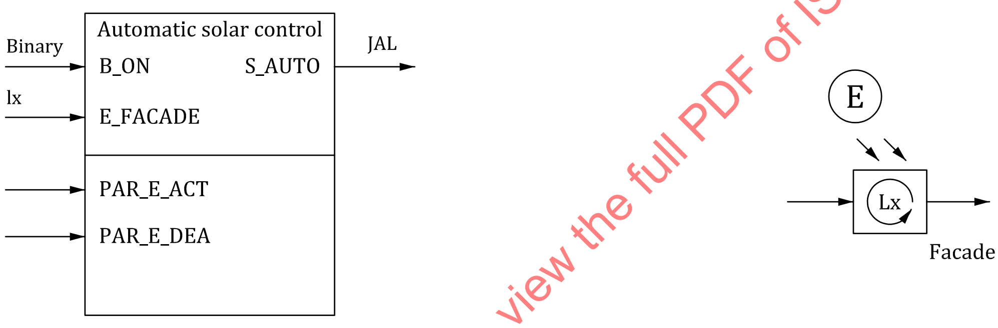
a) b)

Figure B.20 — APPLICATION FUNCTION: "Daylight dependent lighting actor"

— Automatic Solar Control

The "Automatic solar control" application function, shown in Figure B.21, processes the E_FACADE reading as from Sensor "Brightness Measurement Outside" and derives S_AUTO based on activation limit PAR_E_ACT and deactivation limit PAR_E_DEA. The function is masked by B_ON.

$$S_{\text{Auto}} = \begin{cases} 0 & \text{if } E\_FACADE \geq PAR\_E\_ACT \\ 1 & \text{if } E\_FACADE < PAR\_E\_DEA \end{cases} \tag{B.18}$$



a) b)

Figure B.21 — APPLICATION FUNCTION: "Automatic solar control"

— Slat tracking

The "Slat tracking" application function, shown in Figure B.22 and B.23, processes the E_FACADE reading as from Sensor "Brightness Measurement Outside" and derives S_AUTO based on activation limit PAR_E_ACT and deactivation limit PAR_E_DEA. The function is masked by B_ON. In addition to the "Automatic solar control" application function, it offers sun angle (A_SUN_AZ, AZ_SUN_EL) dependent control of slat angles of venetian blinds. Here a commonly used strategy is the "cut-off" control. As function of the profile angle:

$$PROFILE\_ANGLE = \text{atan}\left(\frac{\sin(AZ\_SUN\_EL)}{\cos(AZ\_SUN\_EL) \times \cos(AZ\_SUN\_AZ)}\right) \tag{B.19}$$

the slats incline is controlled such that direct light is just blocked, but the blinds remain opened to the biggest extend, still allowing a diffuse illumination. A typical functional relation of S_AUTO_SLAT_ANGLE = f(PROFILE_ANGLE) is:

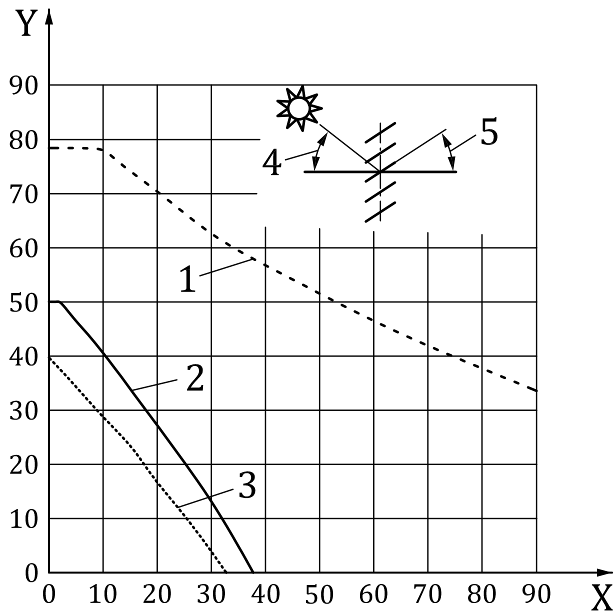
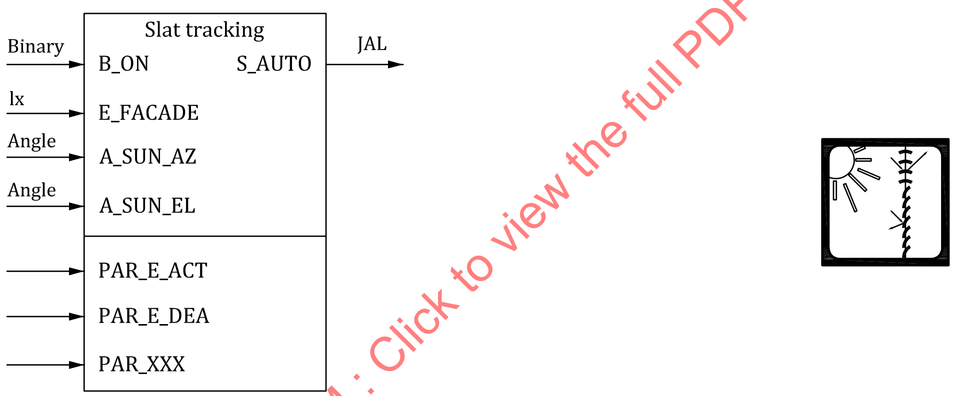


Figure B.22 — APPLICATION FUNCTION: "Slat-tracking" - angular relation between slat angle and solar profile angle[19]



a) b)

Figure B.23 — APPLICATION FUNCTION: "Slat tracking"

B.5.6 Network application and processing functions

— Time program

The "Time signal" network application and processing function, shown in Figure B.24, gives the current time via network with scheduling.