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ASSESSMENT OF VELUX DAYLIGHT VISUALIZER 2 AGAINST CIE 171:2006 TEST CASES

TEST CASES TO ASSESS THE ACCURACY OF LIGHTING COMPUTER PROGRAMS

Test Cases

5.4 – 5.5 – 5.6 – 5.7 – 5.9

5.10 – 5.11 – 5.12 – 5.13 – 5.14

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ASSESSMENT OF VELUX DAYLIGHT VISUALIZER 2 AGAINST CIE 171:2006 TEST CASES

Abstract

VELUX Daylight Visualizer 2 is a software tool dedicated to daylighting design and analysis. It simulates daylight transport in buildings to aid professionals by predicting and documenting daylight levels and appearance of a space prior to realization of the building design. The software permit generation of 3D models in which roof and facade windows are freely inserted. Other settings include the location and orientation of the models, the date and time of the simulation, as well as the sky type (from clear to overcast). In addition to photorealistic rendering, the simulation output includes luminance, illuminance and daylight factor maps.

Like any light transport software, the critical question is whether VELUX Daylight Visualizer 2 produces trustable simulations the user can be confident in. A key point to answer this question is to assess the software capability to simulate the light transport in a physically correct way.

VELUX Daylight Visualizer 2 uses Dali - Luxion light transport algorithms.

The objective of this report is to present the results of the assessment of VELUX Daylight Visualizer 2 against test cases 5.4 – 5.5 – 5.6 – 5.7 – 5.9 – 5.10 – 5.11 – 5.12 – 5.13 – 5.14 (Test Cases to Assess the Accuracy of Lightning Computer Program). The test methodology is based on the comparison of simulation results to analytical reference, for different aspects of the light propagation. The selected test cases correspond to all the situations of CIE 171:2006 validation process where natural lighting is involved. The original CIE document the current study is based on is [CIE, 2006].

Internally, various light transport algorithms are involved in VELUX Daylight Visualizer 2. The settings of each algorithm impact on the simulation accuracy and rendering time. This report presents the results obtained for a particular set of settings (denoted by custom) that is detailed. Test cases are presented first, and then test results are given. Tables are given for analytical reference, simulation results and differences (in %) between the simulation results and the analytical reference. The average difference is also indicated. It is also indicated whether the test is passed, based on the ENTPE – DGCB / CNRS expertise in lighting design.

The sections in this report are numbered according to the test case numbers in the original CIE 171:2006 document.

An overview table is also presented at the end of this report, for all the test cases, all the test cases variants, and all the rendering qualities tested.

Definitions

Test case: A given building design scenario associated with reference data, to be used for assessing a given aspect of a lighting simulation.

Reference data: A set of values (calculated or measured) to be used as a reference when assessing the results of a simulation.

Analytical test case: A theoretical building design scenario wherein the reference data can be analytically calculated based on given assumptions (e.g. light source and surface photometry) and physical laws.

Detailed results of the assessment of VELUX Daylight Visualizer 2 against CIE 171:2006 5.4 – 5.5 – 5.6 – 5.7 – 5.9 – 5.10 – 5.11 – 5.12 – 5.13 – 5.14 test cases

Each section is dedicated to a test case. In each section, the test case is described, and the results of the assessment of *VELUX Daylight Visualizer 2* against this test case are given, for a particular set of settings (denoted by *custom*) that is detailed.

Tables are given for analytical reference, simulation results and differences (in %) between the simulation results and the analytical reference. The average difference is also indicated. It is also indicated whether the test is passed, based on the ENTPE – DGCB / CNRS expertise in lighting design. The test cases have been simulated using a bi-Xeon 2.4 GHz computer running Windows XP-64 bits.

5.4 Luminous flux conservation

The objective of this test is to assess the luminous flux conservation between the light source and the internal surfaces of a space. An error in this conservation is equivalent to source of error in the calculated illuminance in a given scenario.

For daylighting simulations, the flux conservation should be verified between the incident luminous flux (in lumens) at an opening surface and the total direct flux reaching the different internal surfaces.

For artificial lighting scenarios, this flux conservation should be assessed between the output flux of a luminaire and the total direct flux reaching the different internal surfaces.

5.4.1 Analytical reference

5.4.1.1 Daylighting scenarios

In theory, in the case of a room with one opening (unglazed) and with black internal surfaces of 0% reflectance, the total direct luminous flux reaching the interior different surfaces ϕ_i, should be equal to the flux arriving at the opening surface ϕ_o:

$$\phi_i = \phi_o \qquad (1)$$

where:

ϕ_o = incident flux = $E_o.S_o$ (lm)

E_o = average illuminance at the opening surface (lx)

S_o = area of the opening surface

ϕ_I = total direct flux transmitted by the aperture = $\sum F_n = \sum E_n \times S_n$,

ϕ_n = luminous flux reaching the internal surface n (lm)

E_n = average illuminance of the surface n (lx)

S_n = area of the surface n (m²)

5.4.1.1 Artificial lighting scenarios

For an artificial lighting scenario, F_i is equal to the output flux associated with the luminaire.

5.4.2 Test case description

5.4.2.1 Daylighting scenarios

The luminous flux arriving at an opening surface depends on the sky model used by the program to be tested and can vary from one program to another. However, the flux conservation remains valid.

We have defined a sequence of geometries that can be used to verify whether this conservation is achieved for roof openings and for wall openings, and if it is affected by the size of the openings.

The geometry is a square room of dimensions 4m x 4m x 3m, with either a roof or a side opening at the centre of the roof or the wall. The roof opening sizes are 1m x 1m, 2m x 2m, 3m x 3m or 4m x 4m (full opening) with a thickness of 200 mm. The wall opening sizes are 2m x 1m, 3m x 2m or 4m x 3m (full opening) with a thickness of 200 mm.

The lighting simulation should be carried out with black interior surfaces (0% reflectance) to avoid the inter-reflection errors, and with no exterior ground reflections in the case of wall openings (0% external ground reflectance).

If the program being tested does not allow the direct lighting to be considered separately, knowing that some lighting programs attribute finite positive or negative additional values (called epsilon, or ε) to extreme reflectance values (close to 0% or to 100%), a possible source of error due to ε attributed to the 0% reflectance of black surfaces should be taken into consideration. The average error due to ε is equal to the related average indirect illuminance, is given by the following relation:

$$Er_{\varepsilon} = \frac{\varepsilon}{1-\varepsilon} \times \frac{\phi_0}{S_T} \qquad (2)$$

where:

S_T = room total internal surface area

Whatever sky condition is used, the resulting horizontal or vertical illuminance (on the roof surface or on an exterior wall surface) should be calculated and verified to be uniform in order to multiply this illuminance by the opening surface area to get the total flux ϕ_o incident at the opening surface (where $\phi_o = E_o \times S_o$)

The average illuminance for the different interior surfaces, including the opening thickness, should then be measured to calculate the total flux ϕ_i that entered the room (where $\phi_i = \sum E_n \times S_n$).

5.4.2.2 Artificial lighting scenarios

The test case described for the flux conservation in daylighting scenarios can be applied to artificial lighting scenarios by using a closed room (no opening) and any type of luminaire.

5.4.3 Analytical solution

In theory, ϕ_i / ϕ_o should be equal to 1. If $R_S = \phi_i / \phi_o$ for the simulation results, the relation $100 \times (R_S - 1)$ can be used to calculate the error in percentage due to the reduction or increase in the transmitted flux.

5.4.4 Assessment results

5.4.4.1 Test case 5.4 assessment results for a roof opening of 1 m x 1 m

Test case 5.4 **Rendering quality (custom)**

Visualizer 2 slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

Φi / Φo for a roof opening of 1 m x 1 m

Opening type / Luminaire type	Φi / Φo Analytical	Rs = Φi / Φo Simulation	error (%) 100(Rs - 1)
Roof 1 m x 1 m	1	0.993	-0.747

Average difference (%) **0.747**

Test status **Passed**

5.4.4.2 Test case 5.4 assessment results for a roof opening of 2 m x 2 m

Test case 5.4 **Rendering quality (custom)**

Visualizer 2 slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

Φi / Φo for a roof opening of 2 m x 2 m

Opening type / Luminaire type	Φi / Φo Analytical	Rs = Φi / Φo Simulation	error (%) 100(Rs - 1)
Roof 2 m x 2 m	1	1.000	-0.041

Average difference (%) **0.041**

Test status **Passed**

5.4.4.3 Test case 5.4 assessment results for a roof opening of 4 m x 4 m

Test case 5.4 **Rendering quality (custom)**

Visualizer 2 slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

Φi / Φo for a roof opening of 4 m x 4 m

Opening type / Luminaire type	Φi / Φo Analytical	Rs = Φi / Φo Simulation	error (%) 100(Rs - 1)
Roof 4 m x 4 m	1	1.002	0.178

Average difference (%) **0.178**

Test status **Passed**

5.4.4.4 Test case 5.4 assessment results for a wall opening of 2 m x 1 m

Test case 5.4 **Rendering quality (custom)**

Visualizer 2 slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

Φi / Φo for a wall opening of 2 m x 1 m

Opening type / Luminaire type	Φi / Φo Analytical	Rs = Φi / Φo Simulation	error (%) 100(Rs - 1)
Wall 2 m x 1 m	1	1.004	0.410

Average difference (%) **0.410**

Test status **Passed**

5.4.4.5 Test case 5.4 assessment results for a wall opening of 3 m x 2 m

Test case 5.4 **Rendering quality**

Visualizer 2 slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

Φi / Φo for a wall opening of 3 m x 2 m

Opening type / Luminaire type	Φi / Φo Analytical	Rs = Φi / Φo Simulation	error (%) 100(Rs - 1)
Wall 3 m x 2 m	1	0.995	-0.485

Average difference (%) **0.485**

Test status **Passed**

5.4.4.6 Test case 5.4 assessment results for a wall opening of 4 m x 3 m

Test case 5.4 **Rendering quality (custom)**

Visualizer 2 slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

Φi / Φo for a wall opening of 4 m x 3 m

Opening type / Luminaire type	Φi / Φo Analytical	Rs = Φi / Φo Simulation	error (%) 100(Rs - 1)
Wall 4 m x 3 m	1	1.004	0.364

Average difference (%) **0.364**

Test status **Passed**

5.5 Directional transmittance of clear glass τ

The objective of this test case is to assess the capability of a lighting program to take this directional transmittance into consideration. The importance of this test is related to the influence that a glazing material can have on the luminous flux transfer in a daylighting scenario.

The light transmission through glass materials varies with the angle of incidence at which light arrives at the glass surface. This directional transmittance affects the resulting illuminance distribution inside a building. For instance, it significantly reduces illuminance next to a window, or far to the side of a horizontal roof aperture.

5.5.1 Analytical reference

The directional transmittance of a glass at a given incidence angle can be calculated based on the Fresnel's equations.

Nevertheless, there exist in the literature a number of empirical and analytical references that have been proposed to simplify the description of the directional transmittance of different glass types.

Although these references do not differ considerably from each other, it is more convenient to assess a lighting program by comparing its results to the equation it is supposed to use for each type of glass.

For this test case, and as an example, we use an analytical equation proposed by Shlick for a clear glass [Shlick, 1993]. This equation does not take the absorption (due to the composition and the thickness of the glass) into consideration.

$$\tau_\theta \approx 1 - (R_0 + (1 - R_0)(1 - \cos\theta)^5) \quad (3)$$

where:

θ = incidence angle

τ_θ = directional transmittance for the incidence angle θ

R_0 = reflectance at normal incidence (0.04 for clear glass)

5.5.2 Test case description

The geometry used for this test is a square room of dimensions 4m x 4m x 3m, with a roof opening of 1m x 1m at the center of the roof and with a thickness of 200 mm. At the top of the opening is positioned a perfectly smooth glass material. The interior surfaces have a reflectance of 0%.

A sequence of simulations are to be carried out with an incoming directional parallel light beam aimed at the opening surface center with an incidence angle (θ) varying from 0 to 90° in 10° steps. For each position of the source, the total direct flux inside the room ($\phi_i = \sum E_n \times S_n$) will be calculated with and without the glass surface.

The directional transmission τ_θ is equal to the total direct luminous flux obtained with the glass material at the opening surface divided by the total direct flux obtained without glass for the incidence angle θ, and it should follow the analytical solutions presented in Table 1.

5.5.3 Analytical solution

For the above mentioned analytical equation, the relation between the directional transmittance τ_θ of a clear glass at a given incidence angle θ and the normal transmittance τ_0 is given by the following table. (N.B. τ_θ does not take the glass absorption into consideration, and τ_θ/τ_0 represents the relative directional transmission.)

$\theta°$	0	10	20	30	40	50	60	70	80	90
τ_θ	0.96	0.96	0.96	0.96	0.96	0.95	0.93	0.84	0.59	0.00
τ_θ/τ_0	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.87	0.61	0.00

Table 1: Clear glass transmittance variation as a function of the incidence angle

5.5.4 Assessment results

Test case 5.5

Rendering quality (custom)

Visualizer 2 slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

Directional transmittance of clear glass

Reference values

θ	0	10	20	30	40	50	60	70	80	90
τθ	0.96	0.96	0.96	0.96	0.96	0.95	0.93	0.84	0.59	0.00
τθ/τ0	1.00	1.00	1.00	1.00	1.00	0.99	0.96	0.87	0.61	0.00

Measured values

θ	0	10	20	30	40	50	60	70	80	90
τθ	0.96	0.96	0.96	0.96	0.95	0.94	0.91	0.83	0.61	0.00
τθ/τ0	1.00	1.00	1.00	0.99	0.99	0.98	0.95	0.86	0.64	0.00

Differences values (%)

θ	0	10	20	30	40	50	60	70	80	90
τθ	0.04	0.02	-0.06	-0.15	-0.63	-0.80	-2.05	-1.31	3.77	0.00
τθ/τ0	-0.34	-0.36	-0.44	-0.53	-1.02	-1.22	-1.54	-1.12	4.15	0.00

Average difference τθ (%) **0.88**

Average difference τθ/τ0 (%) **1.07**

Test status **Passed**

5.6 Light reflection over diffuse surfaces

The objective of this test case is to assess the accuracy of a lighting program in computing the light reflection over diffuse surfaces. The importance of this test is related to the inter reflections of the light inside a room and also to the reflection of daylight on the external ground and masks.

The surfaces of a geometry are usually considered as ideal diffuse. Inter-reflections are therefore calculated by using radiosity methods that are based on configuration and form factor equations. The direct illuminance being calculated first, each illuminated surface is then considered as a diffuse light source redistributing reflected flux towards the other surfaces of the space.

5.6.1 Analytical reference

Analytically, the indirect illuminance received at an elementary surface dS_1 from a perfectly diffuse reflecting surface S_2 is given by the following relation:

$$E_1 = M_2 \times F_{12} \tag{4}$$

where:

E_1 = indirect illuminance received at point 1 from the surface S_2 (lx).

M_2 = Luminous exitance of the diffuse surface (lm/m²).

F_{12} = form factor between the receiving elementary surface dS_1 and the diffuse surface S_2.

Because S_2 is perfectly diffuse, we also have:

$$M_2 = \pi \times L_2 \tag{5}$$

For a first reflection, M_2 depends on the uniform direct illuminance at the surface S_2, so we also have:

$$M_2 = E_2 \times \rho_{S2} \tag{6}$$

where:

E_2 = direct illuminance received on S_2 (lx).

ρ_{S2} = surface reflectance of S_2.

5.6.2 Test case description

The scenario used for this test case is composed of the following elements (see Figures 1, 2 and 3):

- A diffuse and spectrally neutral horizontal surface S_2 representing the ground, that receives uniform direct illuminance due to sun light or a distant light source.
- A vertical receiving surface $S_{1\text{-}v}$ with 0% reflectance representing a wall.
- A horizontal receiving surface $S_{1\text{-}hz}$ with 0% reflectance oriented towards the ground that represents a ceiling adjacent to the wall.

The receiving surfaces $S_{1\text{-}v}$ and $S_{1\text{-}hz}$ do not receive direct illuminance and do not reflect luminous flux, but they receive a portion of the luminous flux diffusely reflected from surface S_2.

To be able to take into consideration the influence of the size of the diffuse surface S_2, three different scenarios are proposed:

5.6.2.1 Surface S2 of 50cm × 50cm

The geometry of this scenario is shown in Figure 1 and has the following description:

- The surface S_2 is centered under the ceiling with a dimension of 50cm × 50cm. It has a reflectance of 80%.
- The vertical receiving surface $S_{1\text{-}v}$ is positioned at 2m from the center of S_2 and has a dimension of 4m wide and 3m high.
- The horizontal receiving surface $S_{1\text{-}hz}$ is positioned 3m above the ground, is oriented toward S_2, is adjacent to $S_{1\text{-}v}$, and has a dimension of 4m × 4m.
- The surfaces $S_{1\text{-}v}$ and $S_{1\text{-}hz}$ are protected from direct illumination and from possible light leakage artefacts (common to most existing radiosity and ray-tracing methods) by an external envelope.
- The primary light source is oriented with an incidence angle of 45° to avoid direct illuminance of $S_{1\text{-}v}$, and to provide uniform horizontal illuminance E_{hz} over S_2.

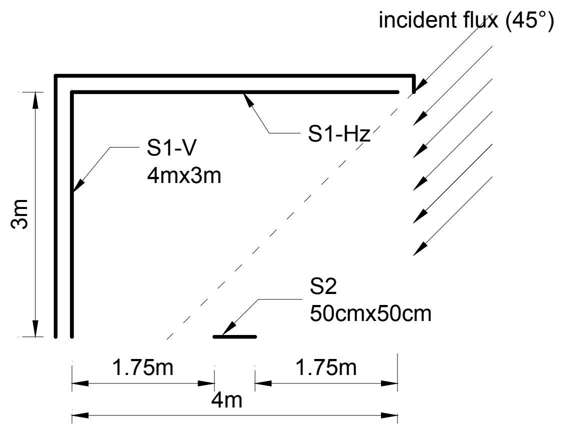


Figure 1: Test case description for S_2 of 50cm×50cm

5.6.2.2 Surface S2 of 4m × 4m

The geometry of this scenario is shown in Figure 2. It is described as follows:

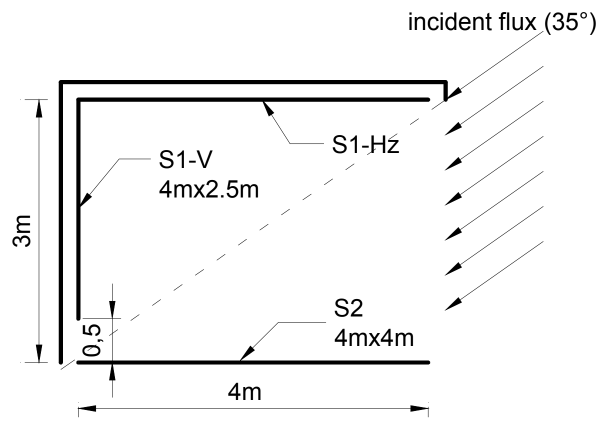


Figure 2: Test case description for S_2 of 4mx4m

- The surface S_2 has a dimension of 4m × 4m. It has a reflectance of 30%.

- The vertical receiving surface $S_{1\text{-}v}$ is positioned 50 cm above the ground (to avoid direct illuminance) and 2m from the centre of S_2, and has a dimension of 4m wide and 2.5m high.
- The horizontal receiving surface $S_{1\text{-}hz}$ is positioned 3m above the ground, is oriented toward S_2, is adjacent to $S_{1\text{-}v}$, and has a dimension of 4m × 4m.
- The surfaces $S_{1\text{-}v}$ and $S_{1\text{-}hz}$ are protected from direct illumination and from possible light leakage by an external envelope.
- The primary light source is oriented with an incidence angle of 35° to avoid direct illuminance on $S_{1\text{-}v}$, and to provide uniform horizontal illuminance E_{hz} over S_2 (see Figure 2).

5.6.2.3 Surface S_2 of 500m × 500m (external ground)

The geometry of this scenario is shown in Figure 3. It is described as follows:

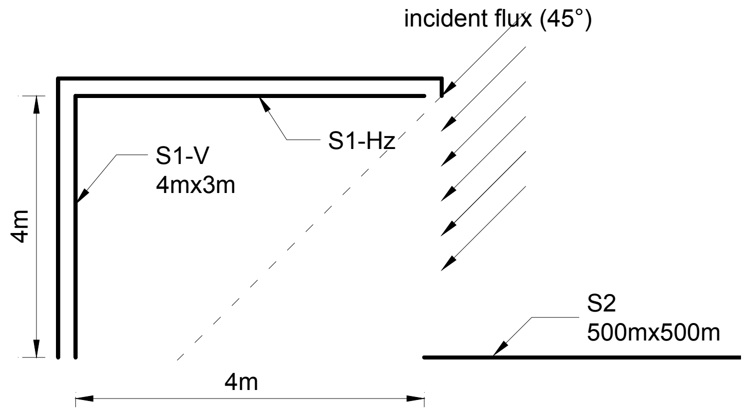


Figure 3: Test case description for S_2 of 500m×500m

- The surface S_2 is 500m × 500m and has a reflectance of 30%.
- The vertical receiving surface $S_{1\text{-}v}$ is positioned 4m above S_2 with the median axis of both surfaces in the same plane. It is 4m wide and 3m high.
- The horizontal receiving surface $S_{1\text{-}hz}$ is positioned 3m above the ground, oriented toward S_2, adjacent to $S_{1\text{-}v}$ and is 4m × 4m.
- The surfaces $S_{1\text{-}v}$ and $S_{1\text{-}hz}$ are protected from direct illumination and from possible light leakage by an external envelope.
- The primary light source is oriented with an incidence angle of 45° to provide uniform horizontal illuminance E_{hz} over S_2.

5.6.2.4 Parametric studies

This test case can be associated with a parametric sensitivity analysis to observe the influence of the source orientation, the horizontal illuminance E_1 and the surface reflectance of S_2 on the accuracy of the results.

5.6.3 Analytical solution

To enable comparison between the simulation results and the analytical reference independently from the illuminance value over S_2 or from its surface reflectance, the reference values are presented in the form of $E / (Ehz \times \rho)$, which is equal to the configuration factor between the measurement point and S_2.

The measurement points at $S_{1\text{-}v}$ and $S_{1\text{-}hz}$ are positioned as shown in Figure 4. The analitycal references are given in tables 2, 3 and 4.

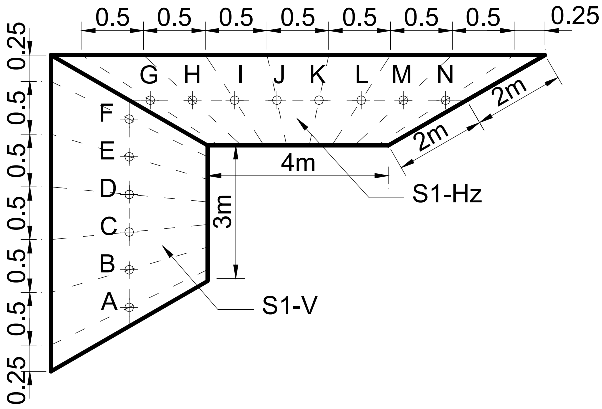


Figure 4: measurement point positions

5.6.3.1 Scenario 1 (S_2: 50 × 50cm)

	Points of measurement for S1-v					
	A	B	C	D	E	F
E/(Ehz×ρ) (%)	0.246	0.580	0.644	0.556	0.433	0.325

	Points of measurement for S1-hz							
	G	H	I	J	K	L	M	N
E/(Ehz×ρ) (%)	0.491	0.639	0.778	0.864	0.864	0.778	0.639	0.491

Table 2: variation of E/(Ehz×ρ) for S2 of 50cm×50cm

5.6.3.2 Scenario 2 (S_2: 4 × 4m)

	Points of measurement for S1-v					
	A	B	C	D	E	F
E/(Ehz×ρ) (%)	-	35.901	27.992	21.639	16.716	12.967

	Points of measurement for S1-hz							
	G	H	I	J	K	L	M	N
E/(Ehz×ρ) (%)	26.80	30.94	33.98	35.57	35.57	33.98	30.94	26.80

Table 3: variation of E/(Ehz×ρ) for S2 of 4m×4m

5.6.3.3 Scenario 3 (S_2: 500 × 500m)

	Points of measurement for S1-v					
	A	B	C	D	E	F
E/(Ehz×ρ) (%)	3.080	9.097	14.718	19.767	24.161	27.896

	Points of measurement for S1-hz							
	G	H	I	J	K	L	M	N
E/(Ehz×ρ) (%)	10.95	13.26	16.21	20.00	24.80	30.77	37.87	45.84

Table 4: variation of E/(Ehz×ρ) for S2 of 500m×500m

5.6.4 Assessment results

5.6.4.1 Test Case 5.6 assessment results for S_2 of 50 cm x 50 cm

Test case 5.6 **Rendering quality (custom)**

Visualizer slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

Variation of E/(Ehz·ρ) for S2 of 50 cm x 50 cm

Reference values

	Reference for S1-hz					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ehz·ρ) (%)	0.246	0.58	0.644	0.556	0.433	0.325

	Reference for S1-hz							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
E/(Ehz·ρ) (%)	0.491	0.639	0.778	0.864	0.864	0.778	0.639	0.491

Measured values

	Points of measurement for S1-hz					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ehz·ρ) (%)	0.172	0.575	0.644	0.560	0.435	0.33

	Points of measurement for S1-hz							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
E/(Ehz·ρ) (%)	0.492	0.640	0.821	0.821	0.852	0.781	0.637	0.492

Differences values (%)

	Differences for S1-hz					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ehz·ρ) (%)	-30.04	-0.88	0.00	0.80	0.45	0.42

	Differences for S1-hz							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
E/(Ehz·ρ) (%)	0.30	0.20	5.49	-5.01	-1.43	0.36	-0.32	0.16

Average difference (%) **3.28**

Test status **Passed**

5.6.4.2 Test Case 5.6 assessment results for S_2 of 4 m x 4 m

Test case 5.6 **Rendering quality (custom)**

Visualizer slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

Variation of E/(Ehz·ρ) for S2 of 4 m x 4 m

Reference values

	Reference for S1-hz					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ehz·ρ) (%)	-	35.901	27.992	21.639	16.716	12.967

	Reference for S1-hz							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
E/(Ehz·ρ) (%)	26.8	30.94	33.98	35.57	35.57	33.987	30.94	26.8

Measured values

	Points of measurement for S1-hz					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ehz·ρ) (%)	45.193	35.916	27.980	21.639	16.725	12.98

	Points of measurement for S1-hz							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
E/(Ehz·ρ) (%)	26.787	30.922	35.553	35.553	35.559	33.962	30.938	26.736

Differences values (%)

	Difference for S1-hz					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ehz·ρ) (%)	-	0.04	-0.04	0.00	0.05	0.10

	Difference for S1-hz							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
E/(Ehz·ρ) (%)	-0.05	-0.06	4.63	-0.05	-0.03	-0.07	-0.01	-0.24

Average difference (%) **0.38**

Test status **Passed**

5.6.4.3 Test Case 5.6 assessment results for S_2 of 500 m x 500 m

Test case 5.6 **Rendering Quality (custom)**

Visualizer slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

Variation of E/(Ehz·ρ) for S2 of 500 m x 500 m

Reference values

	Reference for S1-hz					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ehz·ρ) (%)	3.08	9.097	14.718	19.767	24.161	27.896

	Reference for S1-hz							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
E/(Ehz·ρ) (%)	10.95	13.26	16.21	20	24.8	30.77	37.87	45.84

Measured values

	Points of measurement for S1-hz					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ehz·ρ) (%)	3.047	9.124	14.778	19.846	24.215	27.99

	Points of measurement for S1-hz							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
E/(Ehz·ρ) (%)	10.981	13.287	20.035	20.035	24.851	30.850	37.949	45.980

Differences values (%)

	Difference for S1-hz					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ehz·ρ) (%)	-1.07	0.30	0.41	0.40	0.22	0.35

	Difference for S1-hz							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
E/(Ehz·ρ) (%)	0.28	0.20	23.59	0.17	0.21	0.26	0.21	0.30

Average difference (%) **2.00**

Test status **Passed**

5.7 Diffuse reflection with internal obstructions

The objective of this test case is to verify the capability of a program to simulate the influence of an obstruction to diffuse reflection. The importance of this test is related to the shading influence of internal furniture or to the externally reflected component received from external objects through apertures.

The presence of obstructions presents a higher level of complexity compared to the simulation in "empty room" geometries. Additional errors are introduced that make the simulation results more sensitive to the calculation parameters (radiosity meshing, shadow calculation, et cetera).

5.7.1 Analytical reference

The analytical reference for indirect lighting calculation is the same as the one used for 5.6. However, for this test case, the dimension of the portion of S_2 contributing to the indirect illuminance of a given point has to be calculated according to the position of this point.

5.7.2 Test case description

The scenario used for this test case is composed of the following elements (see Figure 5)

- A vertical diffuse and spectrally neutral surface S_2 representing a wall receiving uniform direct illuminance Ev from sun light or distant light source.
- A vertical receiving surface $S_{1\text{-}v}$ with 0% reflectance representing a wall parallel to S_2
- A horizontal receiving surface $S_{1\text{-}hz}$ with 0% reflectance adjacent to $S_{1\text{-}v}$ and representing the ground
- A vertical obstruction positioned between $S_{1\text{-}hz}$ and S_2 that is parallel to both surfaces

The receiving surfaces $S_{1\text{-}v}$ and $S_{1\text{-}hz}$ do not receive direct illuminance and do not reflect luminous flux, but they receive a portion of the luminous flux diffused by a portion of S_2.

The geometry is shown in Figure 5 and is described as follows:

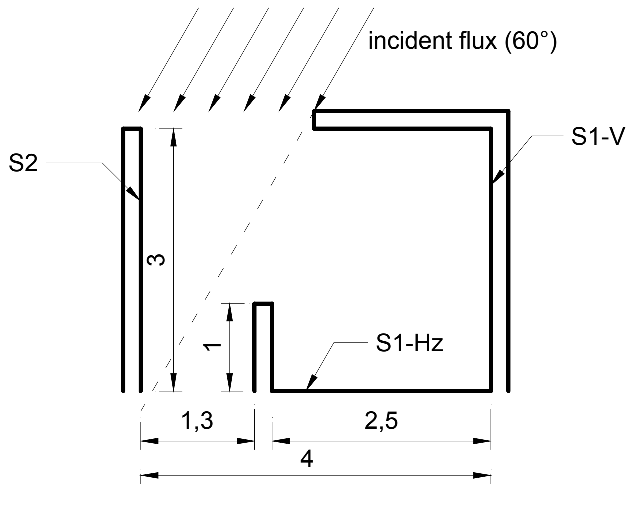


Figure 5: Description of test case with diffuse reflectance and obstruction

The surface S_2 has a dimension of 4m × 3m and a surface reflectance of 60%.

The receiving vertical surface $S_{1\text{-}v}$ has a dimension of 4m × 3m and is positioned to face S_2 at a 4m distance.

The receiving horizontal surface $S_{1\text{-}hz}$ is positioned at ground level, is adjacent to $S_{1\text{-}v}$, and has a dimension of 2.50m × 4m.

The vertical obstruction is 4m wide and 1m high. It has a thickness of 20cm and is positioned at 2.50m from S_{1-v} and 1.30m from S_2.

The surfaces S_{1-v} and S_{1-hz} are protected from direct illumination and from possible light leakage by an external envelope (see Figure 5).

The primary light source is oriented with an incidence angle of 60° to provide uniform vertical illuminance E_v over S_2.

5.7.3 Analytical solution

To enable comparison between the simulation results and the analytical reference independently from the illuminance value over S_2 or from its surface reflectance, the reference values are presented under the form of $E / (Ev \times \rho)$ (see Table 5). This is equal to the configuration factor value between the measurement point and the unobstructed portion of S_2. The measurement points at S_{1-v} and S_{1-hz} are positioned as shown in Figure 6.

The authors of the current study believe the analytical reference given in the original CIE document is erroneous for test case 5.7. The Chief of Project of CIE 171:2006 document (Fawaz Maamari) has been contacted and acknowledged the analytical reference for Test Case 5.7 is certainly erroneous, and explained the CIE will emit an errata. The errors in the analytical reference given by the CIE have been confirmed by another study: [Geisler-Modorer, 2008]. We use the reference given in this study, which includes an analytical demonstration.

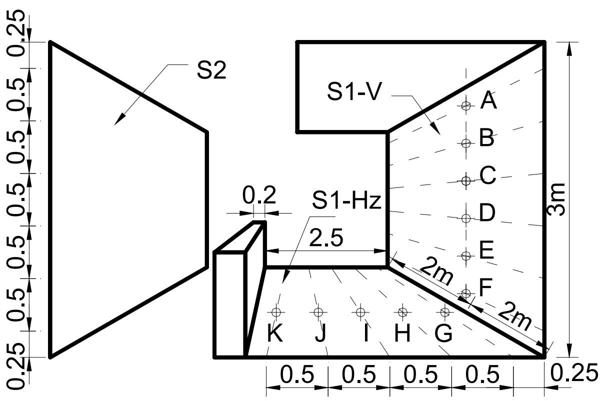


Figure 6: Points of measurement position for internal obstruction test case

	Points of measurement for S1-v					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ev×ρ) (%)	16.07	16.33	15.39	13.32	10.31	7.07

	Points of measurement for S1-hz				
	G	**H**	**I**	**J**	**K**
E/(Ev×ρ) (%)	3.38	3.62	3.01	0.00	0.00

Table 5: Variation of E/(Ev×ρ) for the test case of reflections with internal obstruction

5.7.4. Test Case 5.7 assessment results

Test case 5.7 **Rendering quality (custom)**

Visualizer slider	not used
ambiant	on
trace level	8
ambiant trace level	8
ambiant precision	1
ambiant complexity	10
ambiant feature size	1

Variation of E/(Ev·ρ) for the test case of reflections with internal obstruction

Reference values

	Reference for S1-v					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ev·ρ) (%)	16.07	16.33	15.39	13.32	10.31	7.07

	Reference for S1-hz				
	G	**H**	**I**	**J**	**K**
E/(Ev·ρ) (%)	3.38	3.62	3.01	0.00	0.00

Measured values

	Points of measurement for S1-v					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ev·ρ) (%)	16.00	16.33	15.37	13.26	10.33	7.07

	Points of measurement for S1-hz				
	G	**H**	**I**	**J**	**K**
E/(Ev·ρ) (%)	3.38	3.63	3.00	0.00	0.00

Differences values (%)

	Difference for S1-v					
	A	**B**	**C**	**D**	**E**	**F**
E/(Ev·ρ) (%)	-0.42	0.00	-0.15	-0.44	0.13	-0.09

	Difference for S1-hz				
	G	**H**	**I**	**J**	**K**
E/(Ev·ρ) (%)	0.04	0.15	-0.30	0.00	0.00

Average difference (%) **0.16**

Test status **Passed**

5.9 Sky component for a roof unglazed opening and the CIE general sky types.

The proposed test case aims to test the capability of a lighting program to calculate the sky component under different sky conditions, in particular those standardized by the CIE general sky [CIE, 2003]. The importance of this test is related to the calculation of the daylight factor that is a commonly used parameter for determining daylight availability inside a building.

The daylight factor DF at a certain point P is subdivided as following:

$$DF\ (\%) = SC + ERC + IRC = \frac{E_p}{E_{hz}} \times 100 \qquad (7)$$

where:

SC = sky component

ERC = external reflected component

IRC = internal reflected component

E_p = illuminance at point P

E_{hz} = roof horizontal illuminance (with no obstructions)

In the scenarios tested, the wall thickness is not taken into consideration and no glazing material is used to avoid the related errors.

5.9.1 Analytical reference

The sky component of the daylight factor takes the direct illuminance received at the interior of the room through the aperture from the visible zone of the sky into consideration.

This illuminance varies for a given point according to the luminance distribution of the sky, and the portion of the sky that is visible to the point. This luminance distribution is usually proposed as a standardized sky model. For the CIE general sky types, the direct component can be calculated analytically for the type 16 (CIE overcast sky) and for the type 5 (uniform sky). The algorithms to be used for these two types are described below.

The proposed analytical solution for the other sky types were calculated with a computer program developed for this purpose (*Skylux*), and validated through comparison with the analytical solutions for types 5 and 16. The procedure used subdivides the surface into thousands of sub-surfaces and calculates the average luminance of the sky zone visible through each sub-surface from a given measurement point. The direct illuminance is then calculated by integrating the contribution of each sub-surface. The difference between the program results and the analytical solution (for CIE sky types 5 and 16) is less than 0.1%.

5.9.1.1 Sky component for CIE sky type 5 (uniform)

The sky component under a uniform sky can be calculated by using the configuration factors between the surface opening and the measurement point ($SC = F_{12}$).

In the case of an opening parallel to the receiving surface (ground measurement points), the configuration factor F_{12} between the receiving elementary surface dS_1 representing the measurement point and the surface opening S_2 through which the uniform sky is visible, is given by Equation 6.

In the case of an opening perpendicular to the receiving surface (wall measurement points), the configuration factor F_{12} between the receiving elementary surface dS_1 representing the measurement point and the opening surface S_2 through which the uniform sky is visible, is given by Equation 7.

5.9.1.2 Sky component for CIE sky type 16 (overcast)

The sky component on a horizontal point directly below the corner of a rectangular unglazed opening under a CIE overcast sky is given by the equation [Tregenza, 1993]:

$$SC = \begin{array}{l}[1.5z(d\sin a + c\sin b) + z\pi + z(\sin(2b)\sin c + \sin(2a)\sin d) \\ -2z(\arcsin(\cos\alpha\cos a) + \arcsin(\sin\alpha\cos b))]*100\%\end{array} \quad (8)$$

where:

$$z = \frac{1}{7\pi}$$

$$\alpha = \arctan\left(\frac{\tan a}{\tan b}\right)$$

and angles a, b and c are in radians as shown in Figure 7.

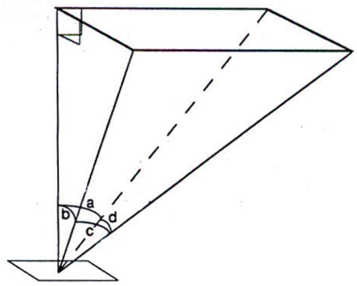


Figure 7: sky component calculation under CIE overcast sky (floor point and horizontal opening)

5.9.2 Description of the test case

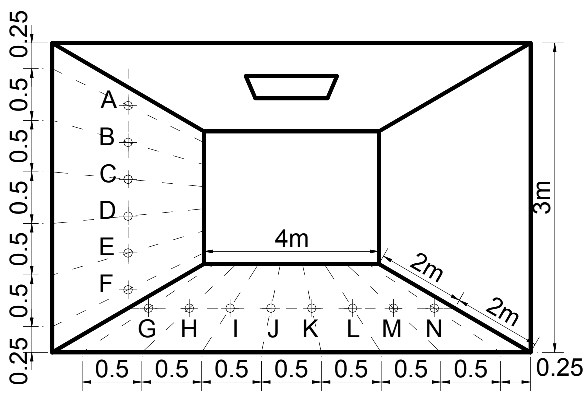


Figure 8: geometry and measurement points description

The geometry used for this test case is a rectangular room of 4m × 4m × 3m, with a roof opening at the centre of the ceiling with a dimension of 1m × 1m or 4m × 4m. The thickness of the roof is not taken into consideration; however an external envelope is recommended to avoid possible light leakage. The internal surfaces are ideal diffuse reflectors with 0% reflectance.

The luminance distribution of the sky is obtained from the CIE general sky equations with the sun position defined on the South (face to the wall reference points) and at 60° elevation. The direct sun illuminance is not taken into consideration.

5.9.3 Analytical solution

The measurement points are positioned as shown in Figure 8. The reference values for this scenario are given in the following sections.

5.9.3.1 Opening of 1m × 1m

Figure 9 below shows a graphical presentation of the analytical reference for CIE sky types 1 (overcast), 9 and 12 (clear).

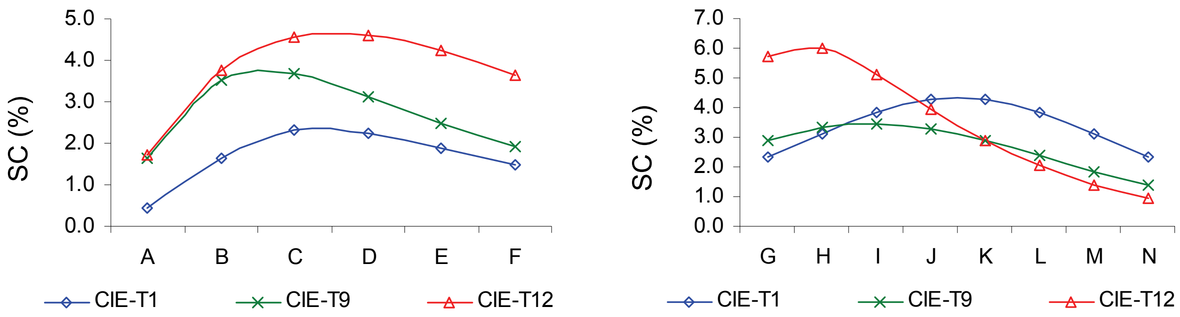


Figure 9: sky component variation under CIE sky types 1, 9 and 12, for a roof unglazed opening of 1m×1m

5.9.3.2 Opening of 4m × 4m

Figure 10 below shows a graphical presentation of the analytical reference for CIE sky types 1, 9 and 12.

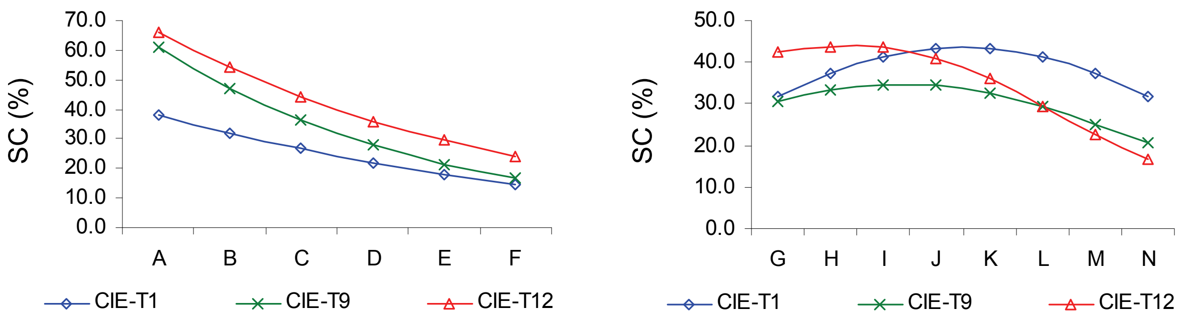


Figure 10: sky component variation under CIE sky types 1, 9 and 12, for a roof unglazed opening of 4m×4m

5.9.4.1 Test Case 5.9 assessment results for a roof opening, size 1 m x 1 m, under CIE general sky types

Test case 5.9 **Rendering quality**

(custom)

Visualizer slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

SC on wall for a roof opening, under CIE general sky types

Reference values

	SC on wall/Reference points					
	A	**B**	**C**	**D**	**E**	**F**
CIE Type 1	0.46	1.64	2.34	2.26	1.88	1.47
CIE Type 2	0.40	1.72	2.86	3.15	2.90	2.44
CIE Type 3	1.36	1.78	2.22	2.46	2.05	0.79
CIE Type 4	0.71	2.17	3.06	3.15	2.79	2.30
CIE Type 5	1.04	2.39	2.59	2.20	1.70	1.27
CIE Type 6	0.94	2.58	3.27	3.16	2.71	2.19
CIE Type 7	0.82	2.52	3.61	3.91	3.69	3.19
CIE Type 8	0.72	2.43	3.86	4.56	4.60	4.18
CIE Type 9	1.64	3.53	3.67	3.14	2.49	1.91
CIE Type 10	1.46	3.52	4.13	3.96	3.45	2.84
CIE Type 11	1.30	3.46	4.49	4.69	4.39	3.79
CIE Type 12	1.74	3.76	4.55	4.61	4.24	3.63
CIE Type 13	1.61	3.76	4.87	5.16	4.89	4.26
CIE Type 14	2.22	4.01	4.88	5.05	4.72	4.08
CIE Type 15	2.14	4.16	5.23	5.47	5.11	4.41

	SC on floor /Reference points							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
CIE Type 1	2.33	3.11	3.84	4.29	3.84	4.29	3.11	2.33
CIE Type 2	4.00	5.00	5.47	5.37	4.73	3.76	2.76	1.90
CIE Type 3	2.13	2.80	3.42	3.81	3.81	3.42	2.80	2.13
CIE Type 4	3.72	4.58	4.97	4.85	4.27	3.42	2.53	1.77
CIE Type 5	1.95	2.52	3.04	3.37	3.37	3.04	2.52	1.95
CIE Type 6	3.47	4.20	4.49	4.36	3.84	3.09	2.31	1.65
CIE Type 7	5.21	5.96	5.70	4.93	3.92	2.90	2.04	1.39
CIE Type 8	6.94	7.65	6.78	5.38	3.93	2.71	1.80	1.17
CIE Type 9	2.88	3.34	3.45	3.29	2.89	2.37	1.83	1.37
CIE Type 10	4.42	4.85	4.49	3.80	3.02	2.27	1.65	1.18
CIE Type 11	6.01	6.36	5.45	4.23	3.09	2.16	1.48	1.01
CIE Type 12	5.72	6.01	5.12	3.97	2.90	2.03	1.40	0.96
CIE Type 13	6.76	7.01	5.80	4.30	2.98	1.99	1.30	0.86
CIE Type 14	6.43	6.64	5.47	4.05	2.81	1.87	1.23	0.82
CIE Type 15	6.94	7.19	5.93	4.36	2.96	1.90	1.20	0.76

Measured values

	SC on wall/measurement points					
	A	**B**	**C**	**D**	**E**	**F**
CIE Type 1	0.45	1.64	2.33	2.25	1.88	1.47
CIE Type 2	0.39	1.72	2.85	3.14	2.91	2.44
CIE Type 3	0.77	2.05	2.46	2.22	1.79	1.37
CIE Type 4	0.69	2.17	3.05	3.14	2.82	2.31
CIE Type 5	1.02	2.39	2.58	2.20	1.71	1.28
CIE Type 6	0.91	2.57	3.25	3.16	2.72	2.18
CIE Type 7	0.81	2.51	3.59	3.91	3.71	3.19
CIE Type 8	0.70	2.43	3.85	4.53	4.62	4.18
CIE Type 9	1.59	3.53	3.66	3.13	2.49	1.90
CIE Type 10	1.42	3.52	4.13	3.95	3.46	2.85
CIE Type 11	1.27	3.45	4.50	4.69	4.41	3.78
CIE Type 12	1.69	3.77	4.53	4.62	4.28	3.63
CIE Type 13	1.57	3.77	4.86	5.16	4.92	4.26
CIE Type 14	2.15	4.01	4.88	5.05	4.75	4.08
CIE Type 15	2.08	4.17	5.23	5.47	5.14	4.39

	SC on floor /measurement points							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
CIE Type 1	2.34	3.09	3.86	4.27	4.29	3.91	3.09	2.33
CIE Type 2	3.98	4.97	5.51	5.35	4.69	3.84	2.74	1.91
CIE Type 3	2.12	2.79	3.45	3.79	3.78	3.49	2.78	2.13
CIE Type 4	3.71	4.56	5.02	4.86	4.23	3.49	2.51	1.77
CIE Type 5	1.95	2.51	3.07	3.36	3.34	3.09	2.51	1.96
CIE Type 6	3.44	4.17	4.54	4.35	3.80	3.15	2.29	1.65
CIE Type 7	5.19	5.92	5.72	4.95	3.87	2.96	2.02	1.39
CIE Type 8	6.92	7.59	6.80	5.38	3.86	2.77	1.78	1.17
CIE Type 9	2.86	3.31	3.48	3.28	2.87	2.41	1.82	1.37
CIE Type 10	4.42	4.80	4.51	3.82	2.99	2.33	1.63	1.17
CIE Type 11	5.99	6.30	5.45	4.24	3.02	2.20	1.47	1.02
CIE Type 12	5.71	5.96	5.15	3.98	2.84	2.07	1.39	0.97
CIE Type 13	6.70	6.96	5.83	4.32	2.91	2.02	1.29	0.86
CIE Type 14	6.43	6.60	5.49	4.05	2.76	1.92	1.23	0.82
CIE Type 15	6.92	7.16	5.94	4.35	2.89	1.95	1.19	0.76

Differences values

	SC on wall/Differences					
	A	B	C	D	E	F
CIE Type 1	-2.86	-0.02	-0.22	-0.56	0.09	-0.32
CIE Type 2	-1.30	0.24	-0.43	-0.30	0.30	-0.13
CIE Type 3	-43.23	15.22	10.76	-9.77	-12.78	72.99
CIE Type 4	-2.57	-0.21	-0.29	-0.25	0.95	0.38
CIE Type 5	-1.95	0.17	-0.49	-0.18	0.34	0.70
CIE Type 6	-3.00	-0.29	-0.48	-0.10	0.45	-0.29
CIE Type 7	-0.77	-0.38	-0.44	-0.05	0.67	0.13
CIE Type 8	-2.43	0.15	-0.37	-0.63	0.39	0.02
CIE Type 9	-3.06	-0.13	-0.23	-0.19	0.12	-0.39
CIE Type 10	-2.75	0.03	0.09	-0.19	0.43	0.28
CIE Type 11	-2.66	-0.28	0.20	0.00	0.47	-0.25
CIE Type 12	-2.66	0.20	-0.36	0.23	0.86	0.12
CIE Type 13	-2.57	0.18	-0.22	0.09	0.63	0.00
CIE Type 14	-3.04	0.04	0.08	-0.09	0.62	0.08
CIE Type 15	-2.61	0.17	0.07	0.08	0.66	-0.53

	SC on floor /Differences							
	G	H	I	J	K	L	M	N
CIE Type 1	0.23	-0.70	0.61	-0.57	11.61	-8.76	-0.66	-0.10
CIE Type 2	-0.55	-0.62	0.81	-0.35	-0.78	2.06	-0.89	0.37
CIE Type 3	-0.49	-0.30	0.83	-0.64	-0.77	2.01	-0.79	-0.04
CIE Type 4	-0.36	-0.49	0.97	0.25	-0.97	1.92	-0.69	0.01
CIE Type 5	-0.23	-0.26	0.87	-0.23	-0.96	1.60	-0.55	0.54
CIE Type 6	-0.93	-0.67	1.20	-0.24	-0.97	1.97	-0.96	-0.21
CIE Type 7	-0.35	-0.64	0.36	0.43	-1.22	2.11	-0.77	-0.26
CIE Type 8	-0.28	-0.85	0.34	0.08	-1.88	2.24	-1.29	0.31
CIE Type 9	-0.55	-0.79	0.92	-0.28	-0.67	1.62	-0.36	0.13
CIE Type 10	-0.06	-0.93	0.37	0.49	-1.14	2.49	-0.92	-0.59
CIE Type 11	-0.35	-0.91	0.01	0.18	-2.11	2.04	-0.44	0.72
CIE Type 12	-0.11	-0.79	0.65	0.33	-1.96	1.85	-0.75	0.67
CIE Type 13	-0.88	-0.66	0.46	0.38	-2.27	1.67	-0.59	0.05
CIE Type 14	-0.04	-0.64	0.37	-0.11	-1.94	2.51	-0.39	-0.32
CIE Type 15	-0.33	-0.48	0.11	-0.31	-2.35	2.59	-0.69	-0.39

Average difference (%) **1.58**

Test status **Passed**

5.9.4.2 Test Case 5.9 assessment results for a roof opening, size 4 m x 4 m, under CIE general sky types

Reference values

	SC on wall/reference points					
	A	**B**	**C**	**D**	**E**	**F**
CIE Type 1	37.84	31.72	26.85	22.1	17.89	14.38
CIE Type 2	42.03	37.03	32.75	28.13	23.7	19.79
CIE Type 3	42.77	34.03	27.43	21.81	17.23	13.61
CIE Type 4	46.85	39.59	33.65	28.08	23.16	19.04
CIE Type 5	46.74	36.05	28.05	21.67	16.73	12.98
CIE Type 6	50.91	41.92	34.58	28.15	22.76	18.41
CIE Type 7	51.83	44.95	38.55	32.55	27.23	22.77
CIE Type 8	52.27	47.46	41.91	36.33	31.13	26.65
CIE Type 9	61.28	47.22	36.33	27.92	21.55	16.78
CIE Type 10	61.85	50.36	40.59	32.56	26.13	21.1
CIE Type 11	61.99	53.01	44.28	36.68	30.26	25.08
CIE Type 12	66.34	54.33	44.25	36.1	29.48	24.25
CIE Type 13	66.63	56.51	47.18	39.24	32.56	27.15
CIE Type 14	71.83	57.51	46.84	38.44	31.62	26.2
CIE Type 15	73.2	60.07	49.66	41.13	34.02	28.29

	SC on wall/reference points							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
CIE Type 1	31.87	37.30	41.27	43.35	43.35	41.27	37.30	31.87
CIE Type 2	42.01	46.99	49.85	50.08	47.76	42.89	36.40	29.02
CIE Type 3	29.16	33.92	37.40	39.22	39.22	37.40	33.92	29.16
CIE Type 4	39.19	43.59	46.07	46.17	43.97	39.50	33.60	26.94
CIE Type 5	26.80	30.95	33.99	35.58	35.58	33.99	30.95	26.80
CIE Type 6	36.63	40.47	42.59	42.57	40.48	36.37	31.03	25.04
CIE Type 7	44.08	47.33	48.53	47.09	43.13	36.83	29.80	22.81
CIE Type 8	50.65	53.33	53.73	51.05	45.38	37.05	28.56	20.78
CIE Type 9	30.70	33.35	34.69	34.41	32.58	29.29	25.19	20.69
CIE Type 10	37.82	39.98	40.52	38.95	35.42	30.18	24.58	19.14
CIE Type 11	44.36	46.04	45.85	43.10	37.95	30.84	23.89	17.68
CIE Type 12	42.33	43.82	43.54	40.85	35.92	29.17	22.62	16.79
CIE Type 13	42.07	48.25	47.47	43.96	37.92	29.91	22.38	15.95
CIE Type 14	44.95	45.99	45.15	41.74	35.96	28.34	21.22	15.16
CIE Type 15	48.42	49.33	48.19	44.25	37.79	29.37	21.53	14.91

Measured values

	SC on wall/measurement points					
	A	B	C	D	E	F
CIE Type 1	35.87	31.53	26.78	22.10	17.87	14.37
CIE Type 2	40.43	36.89	32.67	28.15	23.71	19.77
CIE Type 3	41.02	33.86	27.36	21.81	17.21	13.60
CIE Type 4	45.43	39.46	33.56	28.09	23.18	19.02
CIE Type 5	45.20	35.88	27.97	21.65	16.72	12.99
CIE Type 6	49.68	41.79	34.50	28.15	22.78	18.42
CIE Type 7	51.60	44.93	38.49	32.58	27.27	22.73
CIE Type 8	53.20	47.56	41.84	36.34	31.21	26.60
CIE Type 9	60.41	47.10	36.22	27.92	21.53	16.79
CIE Type 10	62.04	50.46	40.61	32.68	26.22	21.13
CIE Type 11	63.05	53.09	44.22	36.71	30.32	25.06
CIE Type 12	67.43	54.44	44.20	36.14	29.53	24.24
CIE Type 13	68.30	56.67	47.11	39.28	32.65	27.14
CIE Type 14	73.58	57.63	46.77	38.50	31.68	26.16
CIE Type 15	74.99	60.22	49.61	41.16	34.12	28.26

	SC on wall/measurement points							
	G	H	I	J	K	L	M	N
CIE Type 1	31.76	37.26	41.24	43.31	43.30	41.25	37.26	31.83
CIE Type 2	41.90	46.99	49.78	50.07	47.69	42.88	36.35	28.95
CIE Type 3	29.06	33.90	37.35	39.21	39.17	37.38	33.88	29.12
CIE Type 4	39.07	43.56	45.96	46.15	43.91	39.48	33.53	26.89
CIE Type 5	26.74	30.91	33.95	35.56	35.54	33.98	30.92	26.76
CIE Type 6	36.52	40.46	42.50	42.54	40.40	36.37	31.00	25.00
CIE Type 7	43.95	47.33	48.43	47.12	43.09	36.88	29.71	22.77
CIE Type 8	50.47	53.35	53.61	51.10	45.35	37.09	28.49	20.74
CIE Type 9	30.61	33.36	34.64	34.39	32.52	29.31	25.18	20.68
CIE Type 10	37.78	40.09	40.52	39.04	35.43	30.26	24.56	19.13
CIE Type 11	44.22	46.10	45.75	43.16	37.90	30.87	23.81	17.66
CIE Type 12	42.23	43.88	43.47	40.91	35.90	29.20	22.58	16.76
CIE Type 13	46.94	48.33	47.38	44.05	37.88	29.94	22.33	15.92
CIE Type 14	44.86	46.06	45.08	41.80	35.93	28.43	21.17	15.13
CIE Type 15	48.30	49.41	48.10	44.31	37.76	29.47	21.48	14.88

Differences values

	SC on wall/Differences					
	A	B	C	D	E	F
CIE Type 1	-5.20	-0.59	-0.27	-0.02	-0.09	-0.08
CIE Type 2	-3.81	-0.38	-0.24	0.08	0.05	-0.09
CIE Type 3	-4.09	-0.50	-0.26	-0.01	-0.14	-0.04
CIE Type 4	-3.03	-0.32	-0.28	0.02	0.11	-0.12
CIE Type 5	-3.30	-0.46	-0.29	-0.09	-0.07	0.08
CIE Type 6	-2.42	-0.31	-0.24	0.01	0.07	0.08
CIE Type 7	-0.44	-0.05	-0.15	0.08	0.16	-0.18
CIE Type 8	1.78	0.22	-0.17	0.04	0.25	-0.19
CIE Type 9	-1.41	-0.25	-0.29	0.01	-0.08	0.06
CIE Type 10	0.30	0.21	0.04	0.36	0.34	0.14
CIE Type 11	1.71	0.15	-0.13	0.08	0.21	-0.08
CIE Type 12	1.65	0.21	-0.12	0.10	0.17	-0.03
CIE Type 13	2.51	0.29	-0.15	0.10	0.27	-0.03
CIE Type 14	2.43	0.20	-0.14	0.15	0.19	-0.15
CIE Type 15	2.44	0.24	-0.11	0.08	0.28	-0.11

	SC on wall/Differences							
	G	H	I	J	K	L	M	N
CIE Type 1	-0.33	-0.10	-0.08	-0.09	-0.12	-0.06	-0.12	-0.13
CIE Type 2	-0.27	-0.01	-0.14	-0.02	-0.14	-0.02	-0.14	-0.24
CIE Type 3	-0.33	-0.05	-0.14	-0.03	-0.12	-0.06	-0.13	-0.14
CIE Type 4	-0.30	-0.06	-0.23	-0.05	-0.14	-0.04	-0.22	-0.17
CIE Type 5	-0.21	-0.14	-0.12	-0.07	-0.11	-0.04	-0.09	-0.13
CIE Type 6	-0.31	-0.03	-0.21	-0.06	-0.19	0.00	-0.11	-0.16
CIE Type 7	-0.29	0.00	-0.21	0.05	-0.09	0.12	-0.31	-0.17
CIE Type 8	-0.36	0.03	-0.22	0.10	-0.06	0.12	-0.23	-0.19
CIE Type 9	-0.30	0.02	-0.15	-0.05	-0.18	0.05	-0.05	-0.06
CIE Type 10	-0.11	0.27	0.00	0.22	0.04	0.26	-0.09	-0.06
CIE Type 11	-0.31	0.13	-0.22	0.14	-0.14	0.11	-0.32	-0.09
CIE Type 12	-0.23	0.13	-0.16	0.15	-0.05	0.09	-0.17	-0.17
CIE Type 13	11.59	0.17	-0.19	0.19	-0.11	0.08	-0.22	-0.17
CIE Type 14	-0.20	0.15	-0.15	0.15	-0.08	0.30	-0.23	-0.21
CIE Type 15	-0.24	0.17	-0.18	0.15	-0.09	0.33	-0.21	-0.17

Average difference (%) **0.37**

Test status **Passed**

5.10 Sky component under a roof glazed opening

The objective of this test case is to verify the capability of a lighting program to simulate the influence of glass with a given directional transmission under different types of CIE general skies.

The presence of a glazing material over an aperture has a considerable influence on the illuminance distribution inside a room. This influence is related to the directional transmission of normal glazing or to the bi-directional transmission of complex fenestration systems (which are not covered in this test case).

5.10.1 Analytical reference

The directional transmission used is described by the analytical reference proposed by Mitalas and Arseneault for a 6 mm clear glass [Tregenza, 1993]. The reference values (in sky component) are calculated with *Skylux* (see 5.9.1) where the contribution of each subsurface of the window is calculated according to the luminance of the visible zone of the sky and to the glass transmission for the incidence angle between the centre of the subsurface and the measurement point. *Skylux* was validated by comparing its results to the existing analytical reference for clear glass under a CIE overcast sky:

Sky component on the ground under a CIE overcast sky and a 6mm clear glass:

For a floor measurement point, the sky component can be calculated analytically by using the results of Equation 8 multiplied by the average transmission of the glass surface given by the following relation [Tregenza, 1987]:

$$T = \begin{array}{l} 0.623 + 0.3\cos b - 0.137\cos^2 b + 0.51\cos a - 0.66\cos a\cos b \\ + 0.346\cos a\cos^2 b - 0.285\cos^2 a + 0.427\cos^2 a\cos b - 0.246\cos^2 a\cos^2 b \end{array} \quad (9)$$

5.10.2 Test case description

The scenario used for this test case is the same one used for 5.9, but with the presence of 6mm clear glass over the aperture surface.

5.10.3 Analytical solution

The measurement points are positioned as shown in Figure 8. The analitycal reference is given in the following sections.

5.10.4.1 Test Case 5.10 assessment results for a roof opening with 6mm clear glass, size 1 m x 1 m, under CIE general sky types

Test case 5.10	**Rendering quality**	Visualizer slider	not used
	(custom)	ambient	on
		trace level	8
		ambient trace level	8
		ambient precision	1
		ambient complexity	10
		ambient feature size	1

SC on wall for a roof opening, with 6 mm clear glass

Reference values

	SC on wall/Reference points					
	A	**B**	**C**	**D**	**E**	**F**
CIE Type 1	0.15	1.17	1.91	1.92	1.62	1.28
CIE Type 2	0.13	1.22	2.34	2.68	2.50	2.12
CIE Type 3	0.26	1.45	2.01	1.89	1.54	1.18
CIE Type 4	0.24	1.54	2.51	2.68	2.41	2.01
CIE Type 5	0.35	1.69	2.12	1.87	1.47	1.11
CIE Type 6	0.31	1.82	2.67	2.69	2.34	1.90
CIE Type 7	0.28	1.78	2.96	3.33	3.19	2.78
CIE Type 8	0.24	1.73	3.16	3.89	3.98	3.64
CIE Type 9	0.55	2.49	3.00	2.67	2.15	1.66
CIE Type 10	0.49	2.48	3.38	3.37	2.98	2.47
CIE Type 11	0.44	2.45	3.68	4.00	3.79	3.30
CIE Type 12	0.58	2.65	3.72	3.92	3.66	3.16
CIE Type 13	0.54	2.66	3.99	4.40	4.23	3.71
CIE Type 14	0.74	2.83	3.99	4.30	4.08	3.55
CIE Type 15	0.71	2.94	4.28	4.66	4.42	3.84

	SC on floor /Reference points							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
CIE Type 1	2.04	2.73	3.38	3.78	3.78	3.38	2.73	2.04
CIE Type 2	3.50	4.39	4.81	4.72	4.16	3.31	2.42	1.67
CIE Type 3	1.87	2.46	3.01	3.35	3.35	3.01	2.46	1.87
CIE Type 4	3.26	4.03	4.37	4.26	3.76	3.01	2.22	1.55
CIE Type 5	1.71	2.22	2.68	2.96	2.96	2.68	2.22	1.71
CIE Type 6	3.04	3.69	3.95	3.83	3.37	2.72	2.03	1.44
CIE Type 7	4.56	5.23	5.02	4.34	3.45	2.55	1.79	1.22
CIE Type 8	6.08	6.72	5.97	4.73	3.46	2.38	1.58	1.03
CIE Type 9	2.52	2.93	3.04	2.89	2.54	2.08	1.61	1.20
CIE Type 10	3.87	4.26	3.95	3.34	2.65	2.00	1.45	1.03
CIE Type 11	5.26	5.59	4.79	3.72	2.72	1.90	1.31	0.89
CIE Type 12	5.01	5.28	4.51	3.49	2.55	1.79	1.23	0.84
CIE Type 13	5.91	6.16	5.10	3.79	2.62	1.75	1.14	0.75
CIE Type 14	5.63	5.84	4.81	3.56	2.47	1.65	1.08	0.72
CIE Type 15	6.08	6.32	5.22	3.83	2.60	1.68	1.05	0.66

Measured values

	SC on wall/measurement points					
	A	B	C	D	E	F
CIE Type 1	0.22	1.29	1.98	1.96	1.65	1.28
CIE Type 2	0.19	1.34	2.43	2.74	2.55	2.14
CIE Type 3	0.37	1.59	2.08	1.93	1.57	1.20
CIE Type 4	0.33	1.69	2.59	2.75	2.46	2.03
CIE Type 5	0.48	1.85	2.19	1.90	1.49	1.12
CIE Type 6	0.44	2.01	2.76	2.75	2.39	1.93
CIE Type 7	0.38	1.97	3.06	3.41	3.25	2.82
CIE Type 8	0.34	1.91	3.27	3.96	4.06	3.68
CIE Type 9	0.77	2.74	3.10	2.72	2.19	1.68
CIE Type 10	0.69	2.75	3.53	3.43	3.03	2.50
CIE Type 11	0.61	2.70	3.80	4.06	3.86	3.34
CIE Type 12	0.81	2.91	3.86	3.99	3.73	3.20
CIE Type 13	0.74	2.90	4.12	4.47	4.29	3.75
CIE Type 14	1.02	3.11	4.13	4.37	4.15	3.60
CIE Type 15	0.99	3.24	4.43	4.75	4.50	3.88

	SC on floor /measurement points							
	G	H	I	J	K	L	M	N
CIE Type 1	2.05	2.73	3.42	3.77	3.77	3.45	2.73	2.06
CIE Type 2	3.52	4.39	4.88	4.74	4.15	3.39	2.41	1.68
CIE Type 3	1.87	2.47	3.04	3.34	3.34	3.07	2.45	1.88
CIE Type 4	3.27	4.02	4.41	4.28	3.73	3.07	2.21	1.56
CIE Type 5	1.71	2.21	2.71	2.98	2.96	2.75	2.21	1.71
CIE Type 6	3.04	3.68	3.99	3.84	3.36	2.78	2.03	1.45
CIE Type 7	4.56	5.23	5.05	4.37	3.44	2.62	1.79	1.22
CIE Type 8	6.10	6.71	6.00	4.76	3.41	2.43	1.58	1.03
CIE Type 9	2.53	2.93	3.07	2.90	2.52	2.13	1.61	1.21
CIE Type 10	3.87	4.26	3.99	3.37	2.63	2.05	1.45	1.04
CIE Type 11	5.29	5.56	4.83	3.74	2.67	1.95	1.30	0.89
CIE Type 12	5.04	5.28	4.54	3.50	2.51	1.83	1.23	0.85
CIE Type 13	5.95	6.14	5.12	3.81	2.58	1.79	1.14	0.76
CIE Type 14	5.65	5.81	4.83	3.59	2.43	1.68	1.08	0.72
CIE Type 15	6.12	6.32	5.24	3.85	2.55	1.71	1.05	0.67

Differences values

	SC on wall/Differences					
	A	B	C	D	E	F
CIE Type 1	43.37	9.88	3.50	2.18	1.67	0.33
CIE Type 2	43.72	9.85	3.69	2.12	2.04	1.15
CIE Type 3	41.30	9.68	3.65	1.98	1.69	1.80
CIE Type 4	36.21	9.79	3.21	2.48	2.09	0.94
CIE Type 5	38.22	9.64	3.29	1.67	1.64	0.90
CIE Type 6	41.29	10.37	3.50	2.13	1.99	1.45
CIE Type 7	37.13	10.46	3.32	2.38	1.81	1.36
CIE Type 8	41.07	10.30	3.48	1.89	2.00	1.18
CIE Type 9	40.48	10.14	3.38	2.05	1.78	1.43
CIE Type 10	40.75	11.01	4.32	1.74	1.72	1.20
CIE Type 11	37.95	10.27	3.30	1.56	1.79	1.22
CIE Type 12	38.96	9.90	3.64	1.70	1.81	1.30
CIE Type 13	36.74	9.10	3.34	1.54	1.49	1.09
CIE Type 14	37.89	9.78	3.56	1.66	1.61	1.36
CIE Type 15	39.43	10.11	3.46	1.89	1.91	1.04

	SC on floor /Differences							
	G	H	I	J	K	L	M	N
CIE Type 1	0.56	0.16	1.12	-0.26	-0.35	2.15	-0.10	0.87
CIE Type 2	0.55	-0.06	1.45	0.34	-0.21	2.36	-0.22	0.32
CIE Type 3	-0.10	0.22	0.83	-0.24	-0.25	1.94	-0.37	0.38
CIE Type 4	0.33	-0.18	0.97	0.44	-0.77	2.00	-0.50	0.86
CIE Type 5	0.24	-0.43	1.00	0.79	0.14	2.44	-0.37	0.20
CIE Type 6	-0.16	-0.17	1.09	0.22	-0.19	2.03	-0.16	0.97
CIE Type 7	0.07	-0.02	-3.38	-13.02	-20.80	-24.17	-29.86	-31.62
CIE Type 8	0.31	-0.15	0.49	0.71	-1.58	2.31	-0.28	0.40
CIE Type 9	0.21	0.01	1.14	0.18	-0.60	2.22	-0.16	0.51
CIE Type 10	0.12	0.05	0.94	0.98	-0.79	2.61	-0.34	0.77
CIE Type 11	0.59	-0.46	0.76	0.49	-1.94	2.49	-0.75	0.33
CIE Type 12	0.55	0.00	0.69	0.35	-1.68	2.25	-0.06	1.15
CIE Type 13	0.63	-0.33	0.40	0.42	-1.65	2.01	-0.08	0.81
CIE Type 14	0.40	-0.50	0.43	0.74	-1.42	1.99	-0.34	0.20
CIE Type 15	0.71	-0.04	0.29	0.65	-1.81	2.05	-0.21	1.36

Average difference (%) **5.13**

Test status **Passed**

5.10.4.2 Test Case 5.10 assessment results for a roof opening with 6mm clear glass, size 4 m x 4 m, under CIE general sky types

Reference values

	SC on wall/Reference points					
	A	**B**	**C**	**D**	**E**	**F**
CIE Type 1	28.64	25.36	22.25	18.71	15.34	12.45
CIE Type 2	32.75	30.05	27.34	23.90	20.36	17.13
CIE Type 3	30.83	26.68	22.56	18.41	14.76	11.76
CIE Type 4	35.03	31.29	27.90	23.79	19.87	16.46
CIE Type 5	32.66	27.87	22.92	18.23	14.31	11.20
CIE Type 6	37.02	33.01	28.50	23.78	19.50	15.91
CIE Type 7	38.66	35.90	32.00	27.60	23.37	19.69
CIE Type 8	39.78	38.32	34.97	30.89	26.76	23.07
CIE Type 9	41.84	36.14	29.54	23.44	18.41	14.47
CIE Type 10	43.50	39.15	33.27	27.44	22.36	18.22
CIE Type 11	44.66	41.73	36.52	31.00	25.93	21.67
CIE Type 12	46.30	42.34	36.37	30.47	25.25	20.95
CIE Type 13	47.40	44.42	38.91	33.18	27.90	23.46
CIE Type 14	49.09	44.76	38.51	32.46	27.08	22.63
CIE Type 15	50.82	46.97	40.89	34.75	29.15	24.44

	SC on floor /Reference points							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
CIE Type 1	27.88	32.69	36.22	38.07	38.07	36.22	32.69	27.88
CIE Type 2	36.75	41.18	43.74	43.98	41.96	37.67	31.94	25.42
CIE Type 3	25.50	29.73	32.82	34.45	34.45	32.82	29.73	25.50
CIE Type 4	34.27	38.19	40.42	40.55	38.63	34.69	29.48	23.59
CIE Type 5	23.43	27.12	29.83	31.25	31.25	29.83	27.12	23.43
CIE Type 6	32.02	35.45	37.37	37.38	35.56	31.94	27.22	21.92
CIE Type 7	38.53	41.45	42.56	41.35	37.90	32.35	26.15	19.98
CIE Type 8	44.27	46.70	47.12	44.82	39.88	32.56	25.08	18.21
CIE Type 9	26.82	29.20	30.42	30.21	28.61	25.72	22.09	18.10
CIE Type 10	33.03	34.99	35.52	34.19	31.11	26.51	21.56	16.76
CIE Type 11	38.74	40.29	40.19	37.83	33.34	27.10	20.96	15.49
CIE Type 12	36.96	38.34	38.16	35.86	31.56	25.63	19.85	14.71
CIE Type 13	41.10	42.22	41.60	38.58	33.32	26.28	19.65	13.98
CIE Type 14	39.24	40.23	39.57	36.64	31.60	24.91	18.63	13.29
CIE Type 15	42.27	43.16	42.23	38.84	33.21	25.82	18.91	13.07

Measured values

	SC on wall/measurement points					
	A	**B**	**C**	**D**	**E**	**F**
CIE Type 1	28.56	26.30	22.85	19.09	15.57	12.59
CIE Type 2	32.89	31.05	28.01	24.38	20.69	17.32
CIE Type 3	31.59	27.89	23.24	18.80	14.99	11.90
CIE Type 4	35.92	32.87	28.65	24.29	20.19	16.65
CIE Type 5	34.08	29.31	23.66	18.66	14.53	11.35
CIE Type 6	38.56	34.54	29.34	24.30	19.84	16.10
CIE Type 7	40.85	37.44	32.86	28.18	23.78	19.91
CIE Type 8	42.78	39.89	35.84	31.52	27.21	23.29
CIE Type 9	44.99	38.24	30.58	24.02	18.71	14.67
CIE Type 10	47.19	41.38	34.45	28.18	22.81	18.48
CIE Type 11	48.91	43.88	37.63	31.70	26.40	21.94
CIE Type 12	51.16	44.68	37.52	31.19	25.73	21.20
CIE Type 13	52.56	46.77	40.09	33.94	28.40	23.73
CIE Type 14	55.01	47.31	39.74	33.22	27.59	22.89
CIE Type 15	56.73	49.55	42.17	35.54	29.72	24.74

	SC on floor /measurement points							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
CIE Type 1	27.98	32.85	36.34	38.21	38.22	36.37	32.86	28.03
CIE Type 2	36.87	41.43	43.89	44.15	42.08	37.81	32.05	25.52
CIE Type 3	25.62	29.85	32.94	34.56	34.56	32.97	29.86	25.63
CIE Type 4	34.39	38.39	40.54	40.73	38.73	34.83	29.59	23.67
CIE Type 5	23.53	27.25	29.95	31.38	31.35	29.96	27.25	23.55
CIE Type 6	32.12	35.62	37.48	37.53	35.63	32.08	27.32	22.03
CIE Type 7	38.70	41.70	42.71	41.55	37.99	32.51	26.21	20.06
CIE Type 8	44.44	47.02	47.29	45.09	39.99	32.73	25.11	18.25
CIE Type 9	26.92	29.38	30.53	30.33	28.70	25.86	22.18	18.21
CIE Type 10	33.24	35.31	35.72	34.43	31.26	26.68	21.65	16.84
CIE Type 11	38.93	40.60	40.32	38.06	33.47	27.25	21.01	15.55
CIE Type 12	37.16	38.65	38.31	36.09	31.66	25.77	19.89	14.77
CIE Type 13	41.31	42.56	41.77	38.83	33.44	26.44	19.68	14.03
CIE Type 14	39.46	40.56	39.75	36.88	31.70	25.05	18.67	13.34
CIE Type 15	42.50	43.50	42.41	39.10	33.31	25.98	18.93	13.12

Differences values

	SC on wall/Differences					
	A	B	C	D	E	F
CIE Type 1	-0.27	3.70	2.72	2.04	1.49	1.08
CIE Type 2	0.44	3.34	2.46	2.02	1.62	1.12
CIE Type 3	2.47	4.53	3.00	2.11	1.59	1.18
CIE Type 4	2.55	5.06	2.68	2.09	1.59	1.17
CIE Type 5	4.36	5.17	3.25	2.34	1.54	1.32
CIE Type 6	4.16	4.64	2.94	2.19	1.76	1.20
CIE Type 7	5.67	4.30	2.68	2.10	1.74	1.11
CIE Type 8	7.54	4.11	2.50	2.05	1.68	0.95
CIE Type 9	7.54	5.81	3.51	2.48	1.62	1.40
CIE Type 10	8.49	5.70	3.54	2.68	1.99	1.42
CIE Type 11	9.52	5.14	3.04	2.27	1.80	1.25
CIE Type 12	10.50	5.53	3.15	2.35	1.91	1.18
CIE Type 13	10.88	5.30	3.03	2.28	1.81	1.14
CIE Type 14	12.06	5.70	3.20	2.35	1.89	1.13
CIE Type 15	11.63	5.49	3.12	2.26	1.95	1.21

	SC on floor /Differences							
	G	H	I	J	K	L	M	N
CIE Type 1	0.36	0.50	0.33	0.36	0.38	0.42	0.51	0.53
CIE Type 2	0.32	0.61	0.34	0.39	0.28	0.38	0.34	0.38
CIE Type 3	0.46	0.40	0.36	0.33	0.31	0.45	0.44	0.52
CIE Type 4	0.35	0.52	0.31	0.43	0.25	0.40	0.36	0.35
CIE Type 5	0.41	0.49	0.39	0.40	0.33	0.43	0.48	0.52
CIE Type 6	0.31	0.49	0.28	0.40	0.20	0.45	0.37	0.49
CIE Type 7	0.43	0.60	0.34	0.48	0.24	0.49	0.24	0.39
CIE Type 8	0.37	0.68	0.35	0.60	0.26	0.52	0.12	0.24
CIE Type 9	0.39	0.60	0.35	0.39	0.33	0.54	0.41	0.59
CIE Type 10	0.65	0.91	0.57	0.71	0.47	0.64	0.42	0.50
CIE Type 11	0.50	0.78	0.33	0.60	0.38	0.56	0.24	0.41
CIE Type 12	0.53	0.81	0.39	0.63	0.31	0.55	0.22	0.38
CIE Type 13	0.52	0.81	0.40	0.66	0.37	0.60	0.17	0.38
CIE Type 14	0.57	0.82	0.45	0.66	0.33	0.57	0.20	0.34
CIE Type 15	0.53	0.78	0.44	0.66	0.31	0.63	0.08	0.41

Average difference (%) **1.65**

Test status **Passed**

5.11 Sky component and external reflected component for a facade unglazed opening

What differentiates a facade opening from a roof opening is the influence of the external ground on the internal illuminance distribution through the reflection of light toward the ceiling and the wall surfaces.

The objective of this test case is to verify the capability of a program to correctly calculate the contribution of the external ground and the sky luminance distribution to the internal illuminance of a room with a facade opening.

5.11.1 Analytical reference

The analytical reference values are calculated with *Skylux*, which was validated by comparing its results to the analytical reference for a uniform sky and a CIE overcast sky.

5.11.1.1 SC and ERC under a uniform sky

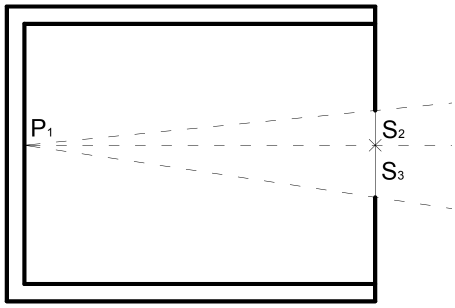


Figure 11: SC and ERC calculation for a facade opening

For the floor measurement points, only the sky component is taken into consideration:

$$SC = F_{12} \quad (10)$$

where:

SC = sky component

F_{12} = configuration factor between the receiving surface dS_1 representing the measurement point P_1 and the zone S_2 of the opening, through which the uniform sky is visible. For a floor point, S_2 is equal to the total opening surface.

For the measurement points on the ceiling, only the external reflected component is taken into consideration. The external ground luminance is assumed to be uniform, and the ERC can therefore be calculated with the following relation:

$$ERC = F_{13} \times \rho \quad (11)$$

where:

ERC = external reflected component.

F_{13} = configuration factor between the receiving surface dS_1 representing the measurement point and the zone S_3 of the opening, through which the external ground is visible. For the ceiling points, S_3 is equal to the total opening surface.

ρ = υniform surface reflectance of the external ground.

For the measurement points on the internal wall facing the opening, and assuming that the internal reflected component is equal to zero, the daylight factor can be calculated with the following equation:

$$DF = SC + ERC = F_{12} + F_{13} \text{ x } \rho \quad (12)$$

5.11.1.2 Sky component on the floor under a CIE overcast sky

The sky component at a horizontal reference point under a CIE overcast sky and a rectangular unglazed façade opening of which the lower side is in the same horizontal plane of the reference point, and of which a vertical side is in a plane perpendicular to the opening surface and passing by the measurement point, is given by the following equation [Tregenza, 1993]:

$$SC = \frac{1.5(b - c\cos a) + 2\arcsin(\sin b \sin a) - \sin 2a \sin c}{7\pi} \times 100\% \qquad (13)$$

where:

a = $\arctan\left(\frac{H}{D}\right)$

b = $\arctan\left(\frac{W}{D}\right)$

c = $\arctan\left(\frac{W}{\sqrt{H^2 + D^2}}\right)$

and the angles a, b and c are in radians as shown in Figure 12.

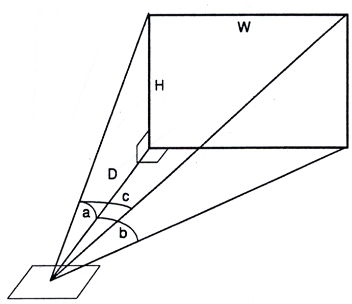


Figure 12: sky component calculation under CIE overcast sky (floor point and vertical opening)

5.11.2 Test case description

The geometry used is a rectangular room of 4m × 4m × 3m with a south façade opening of 2m × 1m or 4m × 3m (as shown in Figure 13). The wall thickness is not taken into consideration. The interior surfaces have a reflectance of 0%.

The luminance distribution of the sky is obtained from the CIE general sky equations with a sun position defined in the South and at 60° elevation. The direct sun illuminance is not taken into consideration.

The external ground is assumed to be uniform luminance and is calculated from the external horizontal illuminance and an external ground reflectance of 30%.

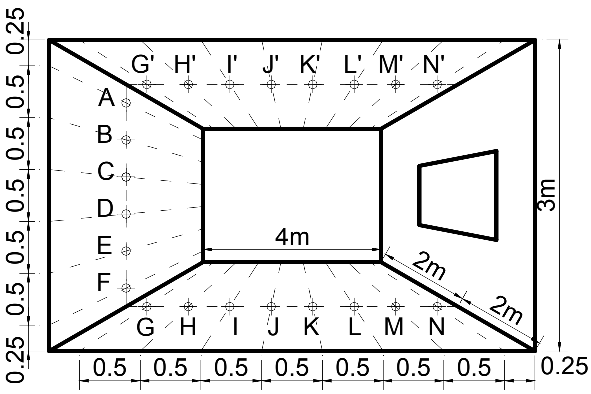


Figure 13: description of geometry and measurement points

5.11.3 Analytical solution

The measurement points are positioned as shown in Figure 13.

5.11.3.1 2m × 1m opening

The reference values (sky component + external reflected component under the sixteen types of the CIE general sky) for this scenario are given in the following sections.

Figure 14 below shows a graphical presentation of the analytical reference for CIE sky types 1, 9 and 12.

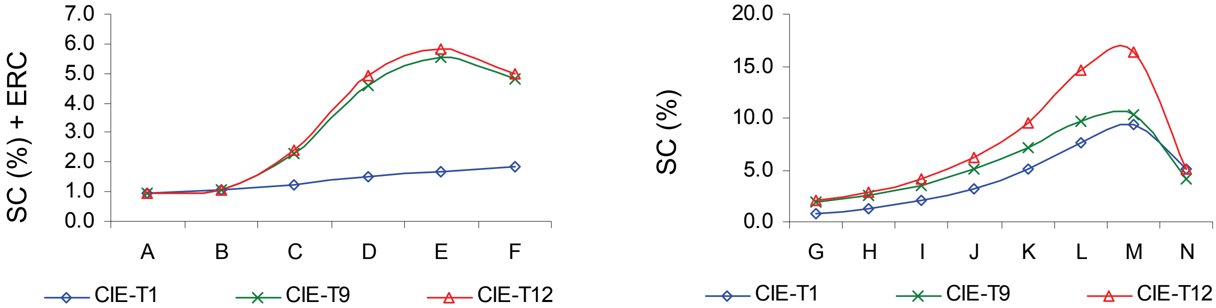
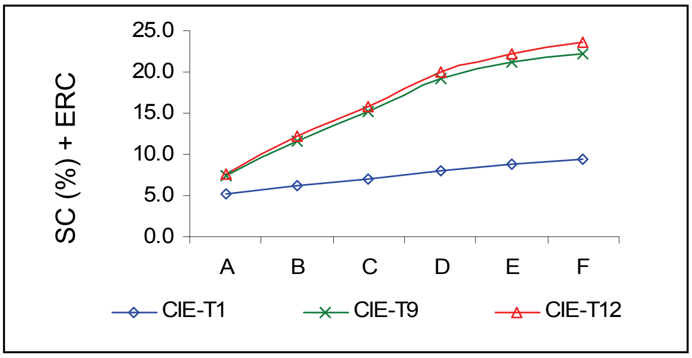


Figure 14: SC and ERC variation under CIE sky types 1, 9 and 12, for a facade unglazed opening of 2m×1m

5.11.3.2 4m × 3m opening

The reference values (sky component + external reflected component under the sixteen types of the CIE general sky) for this scenario are given in the following sections.

Figure 15 below shows a graphical presentation of the analytical reference for CIE sky types 1, 9 and 12.



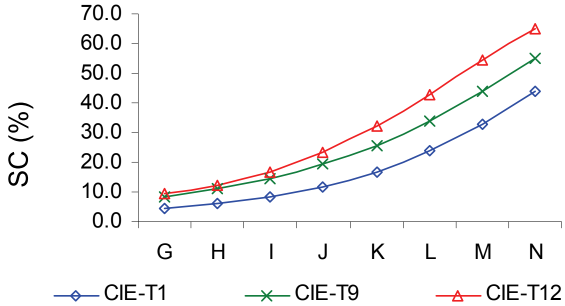


Figure 15: SC and ERC variation under CIE sky types 1, 9 and 12, for a facade unglazed opening of 4m×3m

5.11.4.1 Test Case 5.11 assessment results for a facade opening, size 2 m x 1 m, under CIE general sky types

Test case 5.11 **Rendering quality (custom)**

Visualizer slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

SC + ERC on wall for a facade opening, under CIE general sky types.

Reference values

	SC on wall/Reference points					
	A	**B**	**C**	**D**	**E**	**F**
CIE Type 1	0.95	1.06	1.25	1.51	1.70	1.86
CIE Type 2	0.95	1.06	1.18	1.33	1.55	1.83
CIE Type 3	0.95	1.06	1.56	2.42	2.75	2.58
CIE Type 4	0.95	1.06	1.45	2.14	2.53	2.58
CIE Type 5	0.95	1.06	1.79	3.09	3.54	3.17
CIE Type 6	0.95	1.06	1.65	2.76	3.32	3.22
CIE Type 7	0.95	1.06	1.53	2.43	2.96	3.01
CIE Type 8	0.95	1.06	1.42	2.13	2.64	2.81
CIE Type 9	0.95	1.06	2.27	4.61	5.52	4.82
CIE Type 10	0.95	1.06	2.08	4.10	5.03	4.61
CIE Type 11	0.95	1.06	1.91	3.65	4.56	4.38
CIE Type 12	0.95	1.06	2.39	4.93	5.80	5.01
CIE Type 13	0.95	1.06	2.23	4.52	5.43	4.87
CIE Type 14	0.95	1.06	3.34	6.87	7.12	5.51
CIE Type 15	0.95	1.06	3.17	6.54	6.96	5.58

	SC on floor /Reference points							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
CIE Type 1	0.87	1.31	2.02	3.20	5.07	7.64	9.33	5.09
CIE Type 2	0.92	1.42	2.30	3.86	6.58	10.77	13.66	6.33
CIE Type 3	1.08	1.54	2.26	3.40	5.11	7.34	8.61	4.56
CIE Type 4	1.16	1.71	2.62	4.16	6.73	10.52	12.82	5.80
CIE Type 5	1.27	1.75	2.49	3.59	5.19	7.11	7.99	4.13
CIE Type 6	1.37	1.97	2.92	4.46	6.91	10.33	12.07	5.30
CIE Type 7	1.34	1.98	3.04	4.86	8.04	13.00	15.85	5.97
CIE Type 8	1.30	1.96	3.10	5.16	8.96	15.41	19.39	6.50
CIE Type 9	1.87	2.55	3.55	5.05	7.19	9.74	10.30	4.19
CIE Type 10	1.87	2.61	3.77	5.61	8.50	12.47	13.77	4.81
CIE Type 11	1.84	2.63	3.91	6.04	9.62	15.00	17.13	5.33
CIE Type 12	2.00	2.80	4.06	6.13	9.54	14.57	16.35	5.03
CIE Type 13	2.00	2.85	4.21	6.52	10.43	16.41	18.67	5.43
CIE Type 14	2.14	2.98	4.32	6.55	10.29	15.89	17.82	5.14
CIE Type 15	2.22	3.12	4.57	6.99	11.08	17.18	19.25	5.52

	ERC on ceiling/Reference points							
	G'	**H'**	**I'**	**J'**	**K'**	**L'**	**M'**	**N'**
ERC	0.38	0.53	0.75	1.08	1.56	2.14	2.40	1.24

Measured values

	SC on wall/measurement points					
	A	B	C	D	E	F
CIE Type 1	0.95	1.08	1.21	1.48	1.73	1.85
CIE Type 2	0.95	1.08	1.15	1.30	1.57	1.82
CIE Type 3	0.95	1.08	1.52	2.40	2.79	2.57
CIE Type 4	0.95	1.08	1.40	2.12	2.57	2.57
CIE Type 5	0.95	1.08	1.72	3.07	3.62	3.17
CIE Type 6	0.95	1.08	1.60	2.74	3.36	3.21
CIE Type 7	0.95	1.08	1.47	2.40	3.00	2.99
CIE Type 8	0.95	1.08	1.38	2.11	2.68	2.79
CIE Type 9	0.95	1.08	2.16	4.59	5.63	4.81
CIE Type 10	0.95	1.08	1.98	4.09	5.14	4.59
CIE Type 11	0.95	1.08	1.83	3.61	4.63	4.35
CIE Type 12	0.95	1.08	2.27	4.92	5.92	5.01
CIE Type 13	0.95	1.08	2.12	4.50	5.55	4.86
CIE Type 14	0.95	1.08	3.15	6.86	7.29	5.52
CIE Type 15	0.95	1.08	2.99	6.52	7.10	5.59

	SC on floor /measurement points							
	G	H	I	J	K	L	M	N
CIE Type 1	0.87	1.31	2.02	3.20	5.09	7.63	9.35	5.12
CIE Type 2	0.92	1.42	2.30	3.86	6.58	10.74	13.67	6.33
CIE Type 3	1.08	1.55	2.26	3.39	5.12	7.32	8.64	4.61
CIE Type 4	1.16	1.70	2.61	4.15	6.73	10.48	12.80	5.84
CIE Type 5	1.26	1.75	2.49	3.59	5.19	7.11	8.02	4.17
CIE Type 6	1.37	1.97	2.91	4.46	6.91	10.30	12.10	5.32
CIE Type 7	1.34	1.98	3.03	4.87	8.03	12.96	15.86	5.98
CIE Type 8	1.30	1.96	3.09	5.15	8.94	15.35	19.44	6.49
CIE Type 9	1.87	2.55	3.55	5.04	7.18	9.74	10.30	4.23
CIE Type 10	1.87	2.62	3.78	5.62	8.53	12.45	13.83	4.86
CIE Type 11	1.84	2.63	3.91	6.03	9.59	14.95	17.16	5.36
CIE Type 12	1.99	2.80	4.05	6.11	9.54	14.55	16.35	5.06
CIE Type 13	2.00	2.85	4.21	6.50	10.43	16.36	18.70	5.44
CIE Type 14	2.14	2.97	4.32	6.52	10.28	15.86	17.86	5.15
CIE Type 15	2.21	3.12	4.56	6.98	11.07	17.16	19.30	5.56

	ERC on ceiling/measurement points							
	G'	H'	I'	J'	K'	L'	M'	N'
ERC	0.38	0.53	0.74	1.08	1.56	2.13	2.40	1.23

Differences values

	SC on wall/Differences					
	A	B	C	D	E	F
CIE Type 1	-0.39	1.69	-2.97	-1.67	1.64	-0.53
CIE Type 2	-0.39	1.68	-2.60	-2.25	1.04	-0.31
CIE Type 3	-0.39	1.69	-2.77	-0.88	1.45	-0.48
CIE Type 4	-0.39	1.68	-3.45	-0.79	1.42	-0.54
CIE Type 5	-0.39	1.68	-3.84	-0.60	2.13	0.10
CIE Type 6	-0.39	1.68	-3.24	-0.78	1.34	-0.39
CIE Type 7	-0.40	1.67	-3.64	-1.17	1.19	-0.55
CIE Type 8	-0.40	1.68	-3.10	-0.79	1.51	-0.62
CIE Type 9	-0.40	1.68	-4.74	-0.43	1.98	-0.29
CIE Type 10	-0.40	1.67	-4.62	-0.31	2.16	-0.40
CIE Type 11	-0.41	1.67	-4.36	-0.99	1.52	-0.65
CIE Type 12	-0.40	1.67	-4.96	-0.26	2.09	-0.01
CIE Type 13	-0.40	1.67	-4.97	-0.53	2.24	-0.28
CIE Type 14	-0.37	1.71	-5.56	-0.21	2.46	0.11
CIE Type 15	-0.37	1.71	-5.63	-0.38	1.99	0.21

	SC on floor/Differences							
	G	H	I	J	K	L	M	N
CIE Type 1	0.00	-0.10	-0.09	-0.12	0.30	-0.13	0.21	0.54
CIE Type 2	0.12	0.25	0.08	-0.10	0.05	-0.32	0.10	-0.07
CIE Type 3	0.18	0.39	0.22	-0.18	0.10	-0.20	0.37	1.05
CIE Type 4	-0.19	-0.42	-0.23	-0.27	0.00	-0.35	-0.13	0.69
CIE Type 5	-0.50	0.23	-0.05	-0.02	-0.04	-0.04	0.41	1.09
CIE Type 6	-0.29	-0.07	-0.18	-0.04	0.02	-0.29	0.29	0.46
CIE Type 7	0.03	0.10	-0.33	0.20	-0.07	-0.32	0.06	0.22
CIE Type 8	0.25	0.05	-0.16	-0.14	-0.27	-0.37	0.26	-0.13
CIE Type 9	-0.11	0.00	-0.05	-0.11	-0.10	-0.04	0.01	0.94
CIE Type 10	-0.01	0.50	0.36	0.17	0.31	-0.15	0.40	1.08
CIE Type 11	-0.02	0.13	0.03	-0.08	-0.29	-0.32	0.18	0.59
CIE Type 12	-0.34	-0.03	-0.25	-0.37	0.02	-0.14	0.01	0.64
CIE Type 13	0.11	-0.12	-0.05	-0.36	-0.05	-0.28	0.14	0.15
CIE Type 14	-0.05	-0.40	-0.06	-0.47	-0.08	-0.19	0.23	0.11
CIE Type 15	-0.33	-0.15	-0.26	-0.10	-0.09	-0.11	0.28	0.73

	ERC on ceiling/Differences							
	G'	H'	I'	J'	K'	L'	M'	N'
ERC	0.14	-0.71	-0.83	-0.28	-0.20	-0.39	0.12	-0.82

Average difference (%)	**0.65**
Test status	**Passed**

5.11.4.2 Test Case 5.11 assessment results for a facade opening, size 4 m x 3 m, under CIE general sky types

Reference values

	SC on wall/Reference points					
	A	**B**	**C**	**D**	**E**	**F**
CIE Type 1	5.25	6.11	6.98	7.99	8.77	9.35
CIE Type 2	5.09	5.78	6.56	7.52	8.49	9.35
CIE Type 3	5.93	7.75	9.33	11.09	12.03	12.60
CIE Type 4	5.66	7.23	8.72	10.43	11.64	12.58
CIE Type 5	6.43	8.96	11.11	13.47	14.57	15.17
CIE Type 6	6.10	8.34	10.42	12.76	14.21	15.25
CIE Type 7	5.82	7.72	9.56	11.67	13.19	14.41
CIE Type 8	5.59	7.18	8.81	10.70	12.23	13.57
CIE Type 9	7.42	11.65	15.25	19.22	21.12	22.28
CIE Type 10	7.00	10.71	14.02	17.73	19.81	21.25
CIE Type 11	6.62	9.87	12.91	16.34	18.51	20.18
CIE Type 12	7.63	12.15	15.80	19.96	22.13	23.68
CIE Type 13	7.27	11.39	14.85	18.82	21.13	22.89
CIE Type 14	9.65	15.54	19.50	24.59	26.56	28.04
CIE Type 15	9.25	14.90	18.88	23.94	26.17	27.92

	SC on wall/Reference points							
	G	**H**	**I**	**J**	**K**	**L**	**M**	**N**
CIE Type 1	4.27	5.92	8.33	11.82	16.84	23.83	33.05	44.06
CIE Type 2	4.70	6.71	9.75	14.30	21.00	30.09	41.22	52.94
CIE Type 3	5.09	6.84	9.33	12.87	17.86	24.72	33.68	44.76
CIE Type 4	5.62	7.76	10.91	15.52	22.17	31.06	41.86	53.53
CIE Type 5	5.79	7.63	10.20	13.78	18.76	25.50	34.24	45.29
CIE Type 6	6.43	8.70	11.96	16.65	23.25	31.96	42.44	54.02
CIE Type 7	6.49	8.99	12.70	18.22	26.22	36.60	48.26	59.49
CIE Type 8	6.47	9.14	13.23	19.48	28.80	40.72	53.40	64.13
CIE Type 9	8.36	10.89	14.38	19.18	25.67	33.95	43.73	55.27
CIE Type 10	8.52	11.33	15.32	20.96	28.76	38.52	49.29	60.36
CIE Type 11	8.58	11.61	16.02	22.45	31.52	42.70	54.36	64.85
CIE Type 12	9.26	12.35	16.79	23.17	32.10	43.03	54.44	65.07
CIE Type 13	9.38	12.66	17.43	24.38	34.19	46.11	58.17	68.48
CIE Type 14	10.12	13.45	18.23	25.12	34.76	46.43	58.29	68.51
CIE Type 15	10.48	14.00	19.08	26.41	36.64	48.97	61.35	71.65

	ERC on ceiling/Reference points							
	G'	**H'**	**I'**	**J'**	**K'**	**L'**	**M'**	**N'**
FRE	1.74	2.29	3.06	4.14	5.63	7.65	10.27	13.59

	SC on wall/measurement points					
	A	B	C	D	E	F
CIE Type 1	5.18	6.11	7.02	7.95	8.77	9.37
CIE Type 2	5.04	5.77	6.58	7.52	8.49	9.33
CIE Type 3	5.71	7.74	9.50	10.92	12.02	12.73
CIE Type 4	5.49	7.21	8.82	10.33	11.62	12.65
CIE Type 5	6.11	8.96	11.34	13.21	14.56	15.38
CIE Type 6	5.85	8.32	10.60	12.59	14.19	15.42
CIE Type 7	5.64	7.69	9.70	11.54	13.18	14.51
CIE Type 8	5.45	7.17	8.92	10.61	12.20	13.63
CIE Type 9	6.91	11.64	15.65	18.79	21.10	22.68
CIE Type 10	6.56	10.68	14.36	17.42	19.82	21.64
CIE Type 11	6.26	9.84	13.17	16.07	18.48	20.43
CIE Type 12	7.07	12.11	16.24	19.53	22.10	24.12
CIE Type 13	6.79	11.37	15.22	18.45	21.10	23.25
CIE Type 14	8.68	15.54	20.25	23.82	26.58	28.76
CIE Type 15	8.37	14.91	19.56	23.22	26.17	28.60

	SC on wall/measurement points							
	G	H	I	J	K	L	M	N
CIE Type 1	4.27	5.93	8.33	11.82	16.86	23.81	33.02	44.20
CIE Type 2	4.70	6.73	9.76	14.29	21.01	30.08	41.16	53.45
CIE Type 3	5.08	6.85	9.33	12.86	17.87	24.68	33.58	44.40
CIE Type 4	5.61	7.76	10.92	15.51	22.17	31.04	41.74	53.64
CIE Type 5	5.78	7.64	10.19	13.77	18.76	25.45	34.15	44.57
CIE Type 6	6.42	8.71	11.97	16.62	23.25	31.91	42.35	53.82
CIE Type 7	6.50	9.02	12.71	18.21	26.21	36.61	48.15	59.93
CIE Type 8	6.47	9.16	13.23	19.46	28.80	40.74	53.35	65.25
CIE Type 9	8.33	10.89	14.37	19.14	25.65	33.87	43.58	54.09
CIE Type 10	8.54	11.38	15.36	20.99	28.82	38.56	49.28	60.05
CIE Type 11	8.56	11.63	16.03	22.45	31.50	42.67	54.27	65.15
CIE Type 12	9.25	12.38	16.79	23.16	32.09	42.98	54.29	64.95
CIE Type 13	9.37	12.68	17.43	24.35	34.18	46.09	58.03	68.88
CIE Type 14	10.11	13.47	18.22	25.09	34.72	46.36	58.04	68.63
CIE Type 15	10.46	14.00	19.07	26.38	36.60	48.91	61.10	71.94

	ERC on ceiling/measurement points							
	G'	H'	I'	J'	K'	L'	M'	N'
ERC	1.74	2.29	3.06	4.13	5.63	7.64	10.24	13.36

Differences values

	SC on wall/Differences					
	A	B	C	D	E	F
CIE Type 1	-1.36	-0.01	0.64	-0.54	0.01	0.19
CIE Type 2	-1.02	-0.15	0.26	-0.07	0.01	-0.21
CIE Type 3	-3.71	-0.09	1.77	-1.50	-0.11	1.02
CIE Type 4	-3.01	-0.24	1.19	-0.93	-0.15	0.58
CIE Type 5	-5.01	-0.04	2.10	-1.92	-0.08	1.41
CIE Type 6	-4.09	-0.18	1.75	-1.36	-0.13	1.09
CIE Type 7	-3.13	-0.41	1.49	-1.11	-0.08	0.72
CIE Type 8	-2.47	-0.17	1.24	-0.80	-0.26	0.46
CIE Type 9	-6.90	-0.12	2.62	-2.23	-0.10	1.79
CIE Type 10	-6.22	-0.32	2.42	-1.76	0.06	1.81
CIE Type 11	-5.38	-0.29	2.00	-1.67	-0.18	1.26
CIE Type 12	-7.38	-0.31	2.77	-2.16	-0.14	1.88
CIE Type 13	-6.66	-0.19	2.47	-1.97	-0.14	1.58
CIE Type 14	-10.06	-0.01	3.87	-3.15	0.08	2.59
CIE Type 15	-9.54	0.04	3.58	-3.03	0.01	2.43

	SC on wall/Differences							
	G	H	I	J	K	L	M	N
CIE Type 1	-0.10	0.18	0.00	-0.04	0.12	-0.07	-0.10	0.31
CIE Type 2	0.07	0.32	0.06	-0.09	0.03	-0.04	-0.15	0.96
CIE Type 3	-0.14	0.16	0.05	-0.04	0.06	-0.15	-0.30	-0.81
CIE Type 4	-0.18	0.05	0.07	-0.07	0.02	-0.06	-0.28	0.21
CIE Type 5	-0.20	0.09	-0.10	-0.04	0.00	-0.18	-0.27	-1.58
CIE Type 6	-0.23	0.07	0.10	-0.20	-0.02	-0.16	-0.22	-0.37
CIE Type 7	0.14	0.37	0.08	-0.03	-0.03	0.03	-0.24	0.73
CIE Type 8	-0.05	0.17	0.03	-0.12	0.00	0.04	-0.10	1.74
CIE Type 9	-0.30	0.04	-0.06	-0.18	-0.10	-0.23	-0.35	-2.14
CIE Type 10	0.20	0.44	0.24	0.12	0.21	0.10	-0.03	-0.51
CIE Type 11	-0.21	0.21	0.03	-0.02	-0.06	-0.07	-0.16	0.46
CIE Type 12	-0.12	0.20	0.00	-0.05	-0.02	-0.10	-0.27	-0.18
CIE Type 13	-0.07	0.18	0.02	-0.13	-0.02	-0.05	-0.24	0.59
CIE Type 14	-0.13	0.14	-0.06	-0.11	-0.10	-0.14	-0.44	0.17
CIE Type 15	-0.20	-0.03	-0.06	-0.11	-0.10	-0.13	-0.40	0.41

	ERC on ceiling/Differences							
	G'	H'	I'	J'	K'	L'	M'	N'
ERC	-0.22	0.01	-0.01	-0.20	-0.03	-0.13	-0.25	-1.66

Average difference (%) **0.65**

Test status **Passed**

5.12 SC+ERC for a facade glazed opening

The objective of this test case is to verify the capability of a lighting program to correctly calculate the daylight factor under the sixteen types of the CIE general sky and a glazed façade opening.

5.12.1 Analytical reference

The analytical reference values are calculated with *Skylux*, which was validated by comparing its results to the analytical reference for the sky component under a CIE overcast sky.

Sky component on the floor under a CIE overcast sky and a 6mm clear glass:

For a floor measurement point, the sky component can be calculated analytically by using Equation 13 multiplied by the average transmission of the glass surface given by Equation 9.

5.12.2 Test case description

The scenario used for this test case is the same one used for 5.11, but with 6mm glass over the aperture.

5.12.3 Analytical solution

The measurement points are positioned as shown in Figure 13.

5.12.3.1 2m × 1m opening with a 6mm clear glass

The reference values (sky component + external reflected component under the sixteen types of the CIE general sky) for this scenario are given in the following sections.

5.12.3.2 4m × 3m opening with a 6mm clear glass

The reference values (sky component + external reflected component under the sixteen types of the CIE general sky) for this scenario are given in the following sections.

5.12.4.1 Test Case 5.12 assessment results for a facade opening with a 6 mm clear glass, size 2 m x 1 m, under CIE general sky types

Test case 5.12	Rendering quality (custom)	Visualizer slider	not used
		ambient	on
		trace level	8
		ambient trace level	8
		ambient precision	1
		ambient complexity	10
		ambient feature size	1

SC and ERC on wall for a facade opening (clear glazing), under CIE general sky types.

Reference values

	SC on wall/Reference points					
	A	B	C	D	E	F
CIE Type 1	0.84	0.94	1.10	1.33	1.50	1.63
CIE Type 2	0.84	0.94	1.04	1.17	1.36	1.61
CIE Type 3	0.84	0.94	1.38	2.13	2.42	2.27
CIE Type 4	0.84	0.94	1.27	1.88	2.23	2.27
CIE Type 5	0.84	0.94	1.58	2.72	3.12	2.79
CIE Type 6	0.84	0.94	1.45	2.43	2.92	2.83
CIE Type 7	0.84	0.94	1.34	2.13	2.61	2.65
CIE Type 8	0.84	0.94	1.25	1.88	2.32	2.47
CIE Type 9	0.84	0.94	2.00	4.06	4.86	4.24
CIE Type 10	0.84	0.94	1.83	3.61	4.42	4.05
CIE Type 11	0.84	0.94	1.68	3.21	4.02	3.85
CIE Type 12	0.84	0.94	2.10	4.34	5.11	4.41
CIE Type 13	0.84	0.94	1.96	3.97	4.78	4.29
CIE Type 14	0.84	0.94	2.94	6.04	6.26	4.84
CIE Type 15	0.84	0.94	2.78	5.75	6.12	4.91

	SC on wall/Reference points							
	G	H	I	J	K	L	M	N
CIE Type 1	0.77	1.15	1.77	2.79	4.38	6.44	7.19	2.16
CIE Type 2	0.81	1.25	2.01	3.36	5.67	9.07	10.54	2.70
CIE Type 3	0.95	1.35	1.98	2.96	4.41	6.19	6.64	1.94
CIE Type 4	1.02	1.50	2.29	3.62	5.80	8.86	9.90	2.47
CIE Type 5	1.11	1.54	2.18	3.13	4.47	6.00	6.17	1.75
CIE Type 6	1.20	1.72	2.55	3.88	5.96	8.70	9.33	2.26
CIE Type 7	1.18	1.73	2.66	4.23	6.93	10.95	12.27	2.56
CIE Type 8	1.14	1.72	2.71	4.49	7.72	12.97	15.03	2.79
CIE Type 9	1.64	2.24	3.11	4.40	6.21	8.22	7.97	1.78
CIE Type 10	1.64	2.29	3.30	4.88	7.33	10.51	10.68	2.06
CIE Type 11	1.62	2.31	3.42	5.26	8.29	12.64	13.30	2.29
CIE Type 12	1.75	2.45	3.55	5.34	8.23	12.28	12.69	2.16
CIE Type 13	1.76	2.50	3.69	5.67	9.00	13.82	14.50	2.34
CIE Type 14	1.88	2.61	3.78	5.70	8.87	13.39	13.85	2.21
CIE Type 15	1.95	2.47	4.00	6.09	9.55	14.48	14.96	2.38

	ERC on ceiling/Reference points							
	G'	H'	I'	J'	K'	L'	M'	N'
FRE	0.33	0.46	0.65	0.94	1.34	1.80	1.85	0.53

Measured values

	SC on wall/measurement points					
	A	B	C	D	E	F
CIE Type 1	0.84	0.95	1.07	1.31	1.53	1.63
CIE Type 2	0.84	0.95	1.02	1.16	1.38	1.61
CIE Type 3	0.84	0.95	1.34	2.12	2.46	2.27
CIE Type 4	0.84	0.95	1.24	1.87	2.27	2.26
CIE Type 5	0.84	0.95	1.53	2.71	3.19	2.80
CIE Type 6	0.84	0.95	1.40	2.42	2.98	2.82
CIE Type 7	0.84	0.95	1.30	2.12	2.65	2.65
CIE Type 8	0.84	0.95	1.22	1.86	2.36	2.47
CIE Type 9	0.84	0.95	1.92	4.06	4.96	4.24
CIE Type 10	0.84	0.95	1.75	3.61	4.54	4.06
CIE Type 11	0.84	0.95	1.61	3.20	4.09	3.84
CIE Type 12	0.84	0.95	2.00	4.33	5.22	4.42
CIE Type 13	0.84	0.95	1.87	3.97	4.92	4.30
CIE Type 14	0.84	0.95	2.78	6.05	6.43	4.85
CIE Type 15	0.84	0.95	2.63	5.76	6.27	4.93

	SC on wall/measurement points							
	G	H	I	J	K	L	M	N
CIE Type 1	0.77	1.16	1.78	2.81	4.45	6.58	7.65	2.86
CIE Type 2	0.81	1.26	2.04	3.38	5.76	9.26	11.18	3.56
CIE Type 3	0.96	1.36	2.00	2.98	4.48	6.33	7.06	2.59
CIE Type 4	1.02	1.50	2.30	3.64	5.90	9.06	10.51	3.28
CIE Type 5	1.11	1.55	2.19	3.15	4.54	6.14	6.56	2.33
CIE Type 6	1.21	1.73	2.56	3.91	6.05	8.92	9.91	3.00
CIE Type 7	1.18	1.74	2.67	4.27	7.02	11.18	13.03	3.39
CIE Type 8	1.15	1.73	2.73	4.52	7.84	13.25	15.93	3.70
CIE Type 9	1.64	2.24	3.12	4.43	6.30	8.41	8.45	2.37
CIE Type 10	1.65	2.32	3.33	4.95	7.46	10.76	11.34	2.75
CIE Type 11	1.63	2.33	3.44	5.29	8.42	12.93	14.07	3.04
CIE Type 12	1.76	2.47	3.56	5.39	8.36	12.56	13.46	2.86
CIE Type 13	1.76	2.52	3.71	5.74	9.13	14.13	15.35	3.10
CIE Type 14	1.89	2.63	3.81	5.75	9.00	13.70	14.65	2.91
CIE Type 15	1.96	2.76	4.02	6.15	9.70	14.80	15.87	3.12

	ERC on ceiling/measurement points							
	G'	H'	I'	J'	K'	L'	M'	N'
ERC	0.34	0.46	0.66	0.95	1.36	1.84	1.97	0.70

Differences values

	SC on wall/Differences					
	A	B	C	D	E	F
CIE Type 1	-0.51	1.39	-2.60	-1.30	1.73	-0.06
CIE Type 2	-0.51	1.39	-1.54	-0.95	1.73	0.00
CIE Type 3	-0.51	1.39	-2.54	-0.50	1.77	-0.17
CIE Type 4	-0.51	1.38	-2.65	-0.56	1.82	-0.52
CIE Type 5	-0.51	1.39	-3.18	-0.36	2.28	0.28
CIE Type 6	-0.52	1.38	-3.45	-0.59	1.98	-0.20
CIE Type 7	-0.52	1.38	-2.70	-0.62	1.53	-0.15
CIE Type 8	-0.52	1.38	-2.04	-1.09	1.69	0.12
CIE Type 9	-0.52	1.38	-4.12	-0.08	2.08	0.01
CIE Type 10	-0.52	1.37	-12.40	-11.10	-6.53	-4.26
CIE Type 11	-0.53	1.37	-3.92	-0.32	1.78	-0.17
CIE Type 12	-0.53	1.37	-4.55	-0.17	2.17	0.22
CIE Type 13	-0.52	1.37	-4.84	-0.11	2.91	0.24
CIE Type 14	-0.49	1.41	-5.30	0.14	2.78	0.19
CIE Type 15	-0.49	1.41	-5.22	0.10	2.51	0.49

	SC on wall/Differences							
	G	H	I	J	K	L	M	N
CIE Type 1	-0.01	0.44	0.74	0.69	1.63	2.20	6.33	32.45
CIE Type 2	0.14	0.74	1.36	0.70	1.67	2.07	6.08	32.02
CIE Type 3	0.69	1.09	0.98	0.75	1.65	2.23	6.29	33.33
CIE Type 4	0.18	0.12	0.43	0.43	1.74	2.30	6.12	32.69
CIE Type 5	0.29	0.40	0.51	0.70	1.65	2.30	6.35	33.13
CIE Type 6	0.74	0.77	0.43	0.73	1.58	2.50	6.18	32.65
CIE Type 7	0.20	0.86	0.44	1.05	1.31	2.13	6.16	32.52
CIE Type 8	0.79	0.55	0.91	0.70	1.49	2.12	6.00	32.57
CIE Type 9	0.24	0.16	0.48	0.77	1.38	2.37	5.99	33.22
CIE Type 10	0.35	1.40	0.95	1.38	1.78	2.35	6.16	33.50
CIE Type 11	0.41	0.78	0.62	0.66	1.57	2.31	5.80	32.79
CIE Type 12	0.62	0.88	0.27	0.88	1.61	2.26	6.09	32.24
CIE Type 13	0.21	0.72	0.63	1.17	1.45	2.25	5.89	32.60
CIE Type 14	0.39	0.63	0.81	0.80	1.47	2.35	5.75	31.80
CIE Type 15	0.35	11.59	0.61	0.91	1.56	2.18	6.06	31.16

	ERC on ceiling/Differences							
	G'	H'	I'	J'	K'	L'	M'	N'
ERC	1.70	0.70	0.80	0.59	1.68	2.32	6.45	31.67

Average difference (%) **4.62**

Test status **Passed**

5.12.4.2 Test Case 5.12 assessment results for a facade opening with a 6 mm clear glass, size 4 m x 3 m, under CIE general sky types

Reference values

	SC on wall/Reference points					
	A	B	C	D	E	F
CIE Type 1	4.62	5.38	6.15	7.03	7.72	8.21
CIE Type 2	4.47	5.09	5.78	6.62	7.47	8.22
CIE Type 3	5.21	6.83	8.22	9.76	10.58	11.07
CIE Type 4	4.98	6.36	7.68	9.18	10.24	11.05
CIE Type 5	5.65	7.89	9.78	11.86	12.82	13.34
CIE Type 6	5.36	7.34	9.18	11.24	12.51	13.40
CIE Type 7	5.12	6.79	8.42	10.28	11.60	12.66
CIE Type 8	4.92	6.32	7.76	9.42	10.76	11.93
CIE Type 9	6.53	10.26	13.43	16.92	18.59	19.59
CIE Type 10	6.15	9.43	12.35	15.61	17.43	18.68
CIE Type 11	5.83	8.69	11.37	14.38	16.29	17.74
CIE Type 12	6.71	10.70	13.92	17.58	19.48	20.82
CIE Type 13	6.40	10.03	13.08	16.57	18.59	20.13
CIE Type 14	8.49	13.68	17.17	21.65	23.37	24.65
CIE Type 15	8.14	13.12	16.63	21.08	23.03	24.54

	SC on wall/Reference points							
	G	H	I	J	K	L	M	N
CIE Type 1	3.74	5.17	7.23	10.18	14.30	19.66	25.63	30.02
CIE Type 2	4.11	5.85	8.46	12.30	17.78	24.74	31.91	36.38
CIE Type 3	4.46	5.97	8.11	11.10	15.20	20.48	26.34	31.03
CIE Type 4	4.92	6.77	9.47	13.37	18.82	25.64	32.64	37.32
CIE Type 5	5.07	6.67	8.87	11.91	16.00	21.21	26.96	31.84
CIE Type 6	5.63	7.59	10.39	14.35	19.78	26.47	33.31	38.14
CIE Type 7	5.68	7.84	11.03	15.69	22.26	30.21	37.78	42.18
CIE Type 8	5.66	7.97	11.48	16.76	24.40	33.53	41.74	45.63
CIE Type 9	7.33	9.52	12.51	16.58	21.92	28.33	34.80	40.12
CIE Type 10	7.47	9.90	13.32	18.09	24.51	32.03	39.11	43.91
CIE Type 11	7.51	10.14	13.92	19.35	26.80	35.40	43.03	47.26
CIE Type 12	8.11	10.79	14.60	20.00	27.33	35.75	43.26	47.73
CIE Type 13	8.21	11.05	15.15	21.02	29.08	38.24	46.15	50.26
CIE Type 14	8.87	11.75	15.85	21.69	29.61	38.60	46.41	50.58
CIE Type 15	9.18	12.23	16.59	22.79	31.19	40.68	48.81	52.90

	ERC on ceiling/Reference points							
	G'	H'	I'	J'	K'	L'	M'	N'
FRE	1.52	2.00	2.66	3.57	4.80	6.36	8.09	9.55

Measured values

	SC on wall/measurement points					
	A	B	C	D	E	F
CIE Type 1	4.57	5.40	6.20	7.03	7.73	8.26
CIE Type 2	4.45	5.09	5.80	6.63	7.49	8.24
CIE Type 3	5.05	6.84	8.39	9.65	10.61	11.24
CIE Type 4	4.86	6.35	7.81	9.11	10.26	11.18
CIE Type 5	5.40	7.91	10.02	11.68	12.86	13.59
CIE Type 6	5.15	7.35	9.36	11.11	12.53	13.59
CIE Type 7	4.97	6.80	8.56	10.18	11.62	12.81
CIE Type 8	4.81	6.33	7.85	9.37	10.77	12.03
CIE Type 9	6.11	10.26	13.80	16.62	18.62	20.01
CIE Type 10	5.80	9.42	12.69	15.39	17.48	19.08
CIE Type 11	5.53	8.69	11.63	14.19	16.31	18.02
CIE Type 12	6.24	10.71	14.35	17.23	19.52	21.28
CIE Type 13	6.00	10.03	13.44	16.28	18.63	20.53
CIE Type 14	7.67	13.74	17.89	21.00	23.43	25.40
CIE Type 15	7.39	13.16	17.27	20.51	23.10	25.21

	SC on wall/measurement points							
	G	H	I	J	K	L	M	N
CIE Type 1	3.76	5.21	7.31	10.32	14.59	20.27	27.05	33.03
CIE Type 2	4.14	5.91	8.56	12.49	18.17	25.56	33.71	40.26
CIE Type 3	4.48	6.02	8.19	11.25	15.49	21.07	27.67	33.51
CIE Type 4	4.95	6.84	9.58	13.57	19.20	26.43	34.35	40.71
CIE Type 5	5.09	6.72	8.95	12.04	16.29	21.78	28.24	33.90
CIE Type 6	5.66	7.67	10.51	14.54	20.15	27.23	34.95	41.14
CIE Type 7	5.71	7.92	11.15	15.91	22.71	31.16	39.70	46.02
CIE Type 8	5.70	8.05	11.62	17.00	24.91	34.63	43.91	50.32
CIE Type 9	7.35	9.59	12.64	16.76	22.27	29.05	36.28	42.06
CIE Type 10	7.53	10.02	13.49	18.38	25.02	32.98	40.93	46.82
CIE Type 11	7.55	10.24	14.07	19.60	27.34	36.43	45.03	50.95
CIE Type 12	8.16	10.89	14.74	20.25	27.86	36.76	45.16	50.97
CIE Type 13	8.26	11.16	15.31	21.30	29.64	39.36	48.22	54.12
CIE Type 14	8.90	11.85	16.00	21.94	30.16	39.65	48.32	54.11
CIE Type 15	9.21	12.31	16.75	23.06	31.76	41.81	50.86	56.78

	ERC on ceiling/measurement points							
	G'	H'	I'	J'	K'	L'	M'	N'
ERC	1.53	2.02	2.69	3.61	4.89	6.53	8.47	10.17

	SC on wall/Differences					
	A	B	C	D	E	F
CIE Type 1	-1.17	0.28	0.82	-0.03	0.19	0.60
CIE Type 2	-0.40	0.00	0.30	0.09	0.27	0.24
CIE Type 3	-3.15	0.08	2.06	-1.13	0.27	1.56
CIE Type 4	-2.36	-0.10	1.63	-0.72	0.22	1.14
CIE Type 5	-4.50	0.31	2.49	-1.55	0.28	1.91
CIE Type 6	-3.85	0.18	1.94	-1.13	0.15	1.42
CIE Type 7	-2.88	0.17	1.64	-0.93	0.16	1.19
CIE Type 8	-2.24	0.16	1.21	-0.52	0.14	0.82
CIE Type 9	-6.48	-0.03	2.78	-1.76	0.18	2.14
CIE Type 10	-5.72	-0.09	2.74	-1.41	0.31	2.15
CIE Type 11	-5.13	-0.05	2.31	-1.33	0.11	1.56
CIE Type 12	-6.98	0.06	3.09	-2.00	0.22	2.22
CIE Type 13	-6.31	0.02	2.77	-1.74	0.20	1.99
CIE Type 14	-9.60	0.44	4.19	-3.02	0.24	3.03
CIE Type 15	-9.24	0.29	3.82	-2.70	0.31	2.73

	SC on wall/Differences							
	G	H	I	J	K	L	M	N
CIE Type 1	0.51	0.86	1.10	1.35	2.00	3.09	5.52	10.03
CIE Type 2	0.84	1.10	1.20	1.57	2.18	3.31	5.63	10.65
CIE Type 3	0.43	0.91	0.98	1.35	1.93	2.89	5.06	7.99
CIE Type 4	0.57	0.96	1.18	1.47	2.02	3.09	5.23	9.07
CIE Type 5	0.41	0.81	0.91	1.11	1.82	2.66	4.74	6.46
CIE Type 6	0.48	1.03	1.15	1.33	1.89	2.85	4.92	7.88
CIE Type 7	0.53	1.07	1.10	1.38	2.04	3.13	5.08	9.11
CIE Type 8	0.77	1.07	1.22	1.44	2.09	3.29	5.19	10.27
CIE Type 9	0.25	0.75	1.05	1.08	1.62	2.53	4.24	4.83
CIE Type 10	0.80	1.19	1.29	1.58	2.09	2.97	4.65	6.63
CIE Type 11	0.48	0.96	1.08	1.31	2.02	2.91	4.65	7.82
CIE Type 12	0.56	0.93	0.96	1.25	1.92	2.84	4.39	6.80
CIE Type 13	0.63	0.99	1.05	1.33	1.94	2.93	4.49	7.68
CIE Type 14	0.39	0.87	0.92	1.16	1.87	2.72	4.12	6.97
CIE Type 15	0.32	0.67	0.95	1.19	1.82	2.78	4.20	7.33

	ERC on ceiling/Differences							
	G'	H'	I'	J'	K'	L'	M'	N'
ERC	0.69	0.75	1.03	1.23	1.81	2.74	4.68	6.46

Average difference (%)	**2.32**
Test status	**Passed**

5.13 SC+ERC for an unglazed facade opening with a continuous external horizontal mask

The objective of this test case (and the next one, 5.14) is to verify the capability of a lighting program to simulate the influence of an external mask on the internal direct illuminance. Actually, external masks can influence the internal illuminance distribution inside a building considerably.

The proposed test case assumes the external mask and ground have a uniform luminance in order to calculate the analytical solution. This should be taken into consideration when testing lighting programs that do not support uniform luminance.

The authors of the current study believe the analytical reference given in the original CIE document is erroneous for test case 5.13 and 5.14. The Chief of Project of CIE 171:2006 document (Fawaz Maamari) has been contacted and acknowledged the analytical reference for Test Case 5.13 and 5.14 is certainly erroneous, and explained the CIE will emit an errata. We invite the reader to refer to section '*Proposition of alternative analytical investigation and analytical reference for Test Cases 5.13 and 5.14*' where we explain why we believe the CIE analytical reference is erroneous, and where we show how we obtained an alternative analytical reference that is used for the assessment of VELUX Daylight Visualizer 2.

5.13.1 Test Case description and position of measurement points

The geometry used for this test case is a rectangular room of 4m × 4m × 3m with a façade opening of 2m × 1m at 1m above the floor. The wall thickness is not taken into consideration. No glass material is used.

The external mask is 0.5m, 1m, or 2m high.

The luminance of the mask is assumed to be uniform due to the uniform luminance of the external ground.

Figure 16 illustrates Test Case 5.13 and figure 17 presents the position of the measurement points.

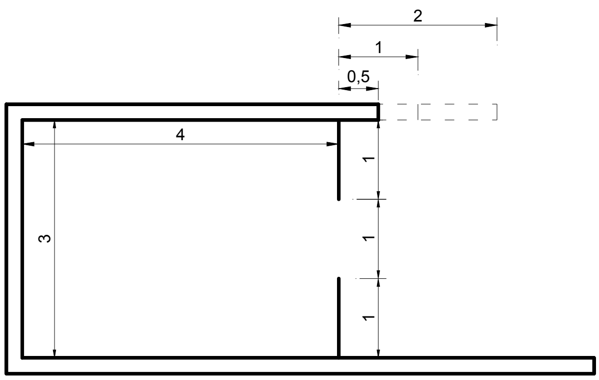


Figure 16: Geometric description for the external horizontal mask test case

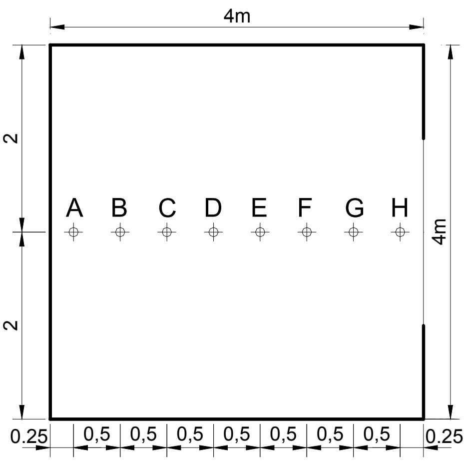


Figure 17: Measurement point positions

5.13.2 Analytical solution

The reader is invited to refer to section '*Proposition of alternative analytical investigation and analytical reference for Test Cases 5.13 and 5.14*'.

The authors of the report decided to take into consideration only Test Case 5.13 variant 2 m long horizontal mask, and to consider only point H that sees a portion of the mask. Indeed, except the partial obstruction of the sky by the horizontal mask (seen by point H), all the aspects of light transport involved in test case 5.13 have already been assessed in Test Case 5.11.

Moreover, the test case will be carried out only for sky type 1, because:
- the sky type only impacts the mask luminance,
- the lighting calculation is linear in the mask luminance, so the analytical reference can be multiplied by any luminance (radiant emittance value) to obtain the lighting corresponding to a given mask luminance,
- the influence of the sky type on the simulated luminance has already been assessed in test cases 5.9 – 5.10 – 5.11 – 5.12.

5.13.4.1 Test Case 5.13 assessment results for a facade opening, with a continuous external 2 meter wide horizontal mask, under CIE sky type 1

Test case 5.13 **Rendering quality (custom)**

Visualizer 2 slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

SC+ERC on floor for a facade opening and horizontal obstruction 2m wide under CIE sky type 1.

Reference values

	SC+ERC on floor/Reference							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
CIE Type 1	-	-	-	-	-	-	-	0.21

Measured values

	SC on wall/measurement points							
	A	B	C	D	E	F	G	**H**
CIE Type 1	-	-	-	-	-	-	-	15

Differences values

	SC on wall/Differences							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
CIE Type 15	-	-	-	-	-	-	-	-26.87

Average difference (%) **4.98**

Test status **Passed**

5.14 SC+ERC for an unglazed facade opening with a continuous external vertical mask

The objective of this test case is to verify the capability of a lighting program to simulate the influence of an external vertical mask on the internal direct illuminance.

The authors of the current study believe the analytical reference given in the original CIE document is erroneous for test case 5.13 and 5.14. The Chief of project of CIE 171:2006 document (Fawaz Maamari) has been contacted and acknowledged the analytical reference for Test Case 5.13 and 5.14 is certainly erroneous, and explained the CIE will emit an errata. We invite the reader to refer to section 'Proposition of alternative analytical investigation and analytical reference for Test Cases 5.13 and 5.14' where we explain why we believe the CIE analytical reference is erroneous, and where we show how we obtained an alternative analytical reference that is used for the assessment of VELUX Daylight Visualizer 2.

5.14.1 Test Case description

The geometry used for this test case is a rectangular room of 4m × 4m × 3m with a façade opening of 2m × 1m at 1m above the floor. The wall thickness is not taken into consideration. No glass material is used.

The external mask is continuous at 6m from the facade and 3m, 6m, or 9m high.

The luminance of the mask is assumed to be uniform due to the uniform luminance of the external ground.

Figure 18 illustrates Test Case 5.14. The measurement point positions are illustrated in Figure 17.

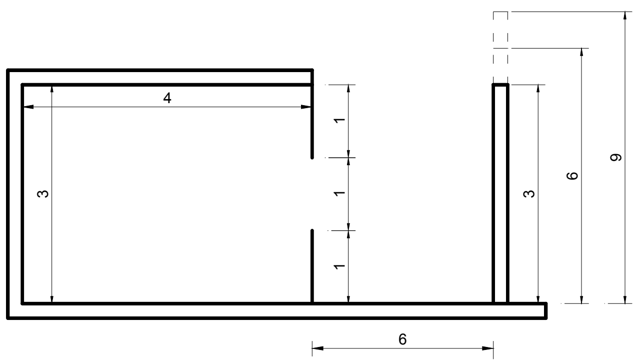


Figure 18: Geometric description for the external vertical mask test case

5.14.2 Analytical reference

The reader is invited to refer to section '*Proposition of alternative analytical investigation and analytical reference for Test Cases 5.13 and 5.14*'.

The authors of the report decided to take into consideration only Test Case 5.14 variant 6 m and 9 m high vertical mask, and to consider only points that see only the mask. Indeed, except the total obstruction of the sky by the vertical mask, all the aspects of light transport involved in test case 5.14 have already been assessed in Test Case 5.12 and 5.13.

That means that only points A and B will be taken into consideration for Test Case 5.14 variant 6 m high vertical mask, and that only points A, B, C and D will be taken into consideration for Test Case 5.14 variant 9 m high vertical mask.

Moreover, the test cases will be carried out only for sky type 1, because:
- the sky type only impacts the mask luminance,
- the lighting calculation is linear in the mask luminance, so the analytical reference can be multiplied by any luminance (radiant emittance value) to obtain the lighting corresponding to a given mask luminance,
- the influence of the sky type on the simulated luminance has already been assessed in test cases 5.9 – 5.10 – 5.11 – 5.12.

5.14.4.1 Test Case 5.14 assessment results for a facade opening, with a continuous external 6 meter high vertical mask, under CIE sky type 1

Test case 5.14 **Rendering quality (custom)**

Visualizer 2 slider	not used
ambient	on
trace level	8
ambient trace level	8
ambient precision	1
ambient complexity	10
ambient feature size	1

SC+ERC on floor for a facade opening and vertical obstruction 6m and 9m high under CIE sky type 1.

Reference values

	SC+ERC on floor/Reference							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
CIE Type 1	0.01262	0.01751	-	-	-	-	-	-

Measured values

	SC on wall/measurement points							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
CIE Type 1	0.01265	0.01749	-	-	-	-	-	-

Differences values

	SC on wall/Differences							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
CIE Type 1	0.26	-0.09	-	-	-	-	-	-

Average difference (%) **0.17**

Test status **Passed**

5.14.4.2 Test Case 5.14 assessment results for a facade opening, with a continuous external 9 meter high vertical mask, under CIE general sky type 1.

Reference values

	SC+ERC on floor/Reference							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
CIE Type 1	0.1262	0.17514	0.2477	0.03582	-	-	-	-

Measured values

	SC on wall/measurement points							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
CIE Type 1	0.01265	0.01749	0.02480	0.03587	-	-	-	-

Differences values

	SC on wall/Differences							
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
CIE Type 15	0.26	-0.09	0.14	0.15	-	-	-	-

Average difference (%) **0.16**

Test status **Passed**

Proposition of alternative analytical investigation and analytical reference for Test Cases 5.13 and 5.14

Analytical Investigation of CIE Test Case 5.14

This section describes the analytical investigation of CIE test case 5.14.

Irradiance due to a polygonal source

The vector irradiance due to a polygonal source is computed as follows:

$$\vec{E}(x) = \frac{M}{2\pi}\sum_{i=1}^{n}\Theta_i(x)\Gamma_i(x)$$

where $\vec{E}$ is the vector irradiance, M is the radiant emittance of the source, $\Theta_i(x)$ is the angular extent of the ith polygon edge as seen from x, and $\Gamma_i(x)$ is the vector normal to the plane spanned by x and the vertices of edge i.

The irradiance is computed as:

$$E(x) = -\vec{E}(x)\cdot\vec{n}(x)$$

where $\vec{n}(x)$ is the surface normal at x.

Analytical Calculation for CIE test case 5.14 (Mask Height is 9m)

We will analyze the case with a mask of height 9m. In this case the points A,B,C, and D only see the mask, and this means that we only need to compute the ERC (reflected light due to the mask).

Furthermore, it is assumed that the mask has constant luminance. This effectively means that the luminance passing through the opening is constant as well (when seen from the points A,B,C, and D). This means that we can compute the illuminance due to a rectangular light at the window opening and this will give the same result as a mask with constant luminance. This is due to the raw law, which states that radiance (or luminance) is constant along any unobstructed line of sight.

We can now use the calculation from the preceding section as follows.

Assume that the measurement point is at the origin. Compute the illuminance due to a rectangular light source with corners (x,−1, 1), (x, 1, 2). Here x is the horizontal distance from the measurement point to the opening. The distances are x(A) = 3.75, x(B) = 3.25, x(C) = 2.75, x(D) = 2.25.

Using the analytical formulas we find that the illuminance values are:

A = 0.0126557 ×M
B = 0.0175407 ×M
C = 0.0248783 ×M
D = 0.0359155 ×M

Consider the calculation for CIE sky type 1. We can use the reference value for A to estimate the luminance of the mask.

$$E_{\text{mask reference}} = 0.77/0.0126557 = 60.84$$

Using this reference value we can compute the illuminance at the points B,C, and D:

$$B = 0.0175407 \times E_{\text{mask reference}} = 1.0672$$
$$C = 0.0248783 \times E_{\text{mask reference}} = 1.5136$$
$$D = 0.0359155 \times E_{\text{mask reference}} = 2.1851$$

The numbers listed in the CIE 171:2006 report as reference values are B = 0.90, C = 1.04, and D = 1.19. These values do not agree with the analytical calculation.

Using Velux Daylight Visualizer 2 on test case 5.14 with a mask of constant luminance $1/\pi$ corresponding to radiant emittance M = 1 we find:

A = 0.0126257
B = 0.0175145
C = 0.0247712
D = 0.0358227

Since the lighting calculation is linear in the mask luminance we can multiply these numbers by any luminance (radiant emittance value) to obtain the lighting corresponding to a given mask luminance.

Analytical Calculation for CIE test case 5.14 (Mask Height is 6m)

In the case of a mask height of 6m only the points A and B see only the mask. The value for these points are the same as in the case of the mask with a height of 9m. Here is the result produced by Velux Daylight Visualizer 2:

A = 0.0126257
B = 0.0175145

Analytical Investigation of CIE Test Case 5.13

This section describes the analytical investigation of CIE test case 5.13.

Test case 5.13 is similar to 5.14 except that the mask is horizontal, and it is partially visible for points H, G, and more depending on the size. Since the mask no longer covers the entire window it is more complicated to compute the irradiance due to the mask. We will therefore only consider the irradiance at point H due to a mask of size 2 meters.

We project the mask onto the wall in the direction of point H. We can clip this projected mask against the opening, and we find that the mask forms a polygon with corners (−1, 2), (1, 2), (1, 3/2), (2/3, 1), (−2/3, 1), (−1, 3/2). The irradiance from this polygonal source onto point H is:

$$H = 0.0380191 \times M$$

Using Velux Daylight Visualizer 2 we find that the contribution of the mask to point H is:

$$H = 0.0383577 \times M$$

Assessment overview of VELUX Daylight Visualizer 2 against CIE 171:2006 5.4 – 5.5 – 5.6 – 5.7 – 5.9 – 5.10 – 5.11 – 5.12 – 5.13 – 5.14 test cases

The test cases have been simulated using a bi-Xeon 2.4 GHz computer running Windows XP-64 bits.

Table 6 details the custom settings used to perform the test cases assessment presented in this report.

VELUX Daylight Visualizer 2 settings	ambient	on
(custom)	trace level	8
	ambient trace level	8
	ambient precision	1
	ambient complexity	10
	ambient feature size	1

Table 6: VELUX Daylight Visualizer 2 custom settings

Assessment overview of VELUX Daylight Visualizer 2 for custom settings

Table 7 gathers the essential information about the results of the assessment of VELUX Daylight Visualizer 2 (custom settings) against test cases 5.4, 5.5, 5.6, 5.7, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14.

Test Case number	Test Case variant	Average error (%)	Test status
Test Case 5.4	Roof opening 1 m x 1 m	0.747	**Passed**
	Roof opening 2 m x 2 m	0.041	**Passed**
	Roof opening 4 m x 4 m	0.178	**Passed**
	Wall opening 2 m x 1 m	0.410	**Passed**
	Wall opening 3 m x 2 m	0.485	**Passed**
	Wall opening 4 m x 3 m	0.364	**Passed**
Test Case 5.5	-	1.070	**Passed**
Test Case 5.6	S_2 of 50 cm x 50 cm	3.280	**Passed**
	S_2 of 4 m x 4 m	0.380	**Passed**
	S_2 of 500 m x 500 m	2.000	**Passed**
Test Case 5.7	-	0.160	**Passed**
Test Case 5.9	Roof opening 1 m x 1 m	1.580	**Passed**
	Roof opening 4 m x 4 m	0.370	**Passed**
Test Case 5.10	Roof opening 1 m x 1 m	5.130	**Passed**
	Roof opening 4 m x 4 m	1.650	**Passed**
Test Case 5.11	Wall opening 1 m x 1 m	0.650	**Passed**
	Wall opening 4 m x 3 m	0.650	**Passed**
Test Case 5.12	Wall opening 1 m x 1 m	4.620	**Passed**
	Wall opening 4 m x 3 m	2.320	**Passed**
Test Case 5.13	2 m horizontal mask	2.050	**Passed**
Test Case 5.14	6 m vertical mask	0.172	**Passed**
	9 m vertical mask	0.158	**Passed**

Table 7: Results of the assessment of VELUX Daylight Visualizer 2 (custom settings) against test cases 5.4, 5.5, 5.6, 5.7, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14.

Mapping between VELUX Daylight Visualizer 2 internal settings and VELUX Daylight Visualizer 2 global rendering quality slider

Let RQ denote the VELUX Daylight Visualizer 2 global Rendering Quality slider value.

The mapping between VELUX Daylight Visualizer 2 internal settings and VELUX Daylight Visualizer 2 global rendering quality slider is as follows:

ambient on	// indirect illumination on or off
trace level 4	// number of bounces of all types of // lighting
ambient trace level 8	// number of bounces of ambient (indirect) // lighting
ambient precision = RQ * 0.2 + 0.5	// this parameter relates to the image // based sampling used

ambient complexity = RQ + 1	// this parameter describes the lighting
	// complexity. It influences the number of
	// samples used. Higher values equals
	// higher precision

ambient feature size depends on RQ	// this parameter relates to the image // interpolation quality

The test cases have been simulated using ambient feature size = 0, since this parameter relates to the image interpolation quality and because no image is used for the assessment.

The mapping between VELUX Daylight Visualizer 2 internal settings and VELUX Daylight Visualizer 2 global rendering quality slider (RQ) is detailed above, for RQ in range [0-10]:

RQ0

Visualizer 2 slider	0
ambient	on
trace level	10
ambient trace level	4
ambient precision	0,5
ambient complexity	1
ambient feature size	0

RQ1

Visualizer 2 slider	1
ambient	on
trace level	10
ambient trace level	4
ambient precision	0,7
ambient complexity	2
ambient feature size	0

RQ2

Visualizer 2 slider	2
ambient	on
trace level	10
ambient trace level	4
ambient precision	0,9
ambient complexity	3
ambient feature size	0

RQ3

Visualizer 2 slider	3
ambient	on
trace level	10
ambient trace level	4
ambient precision	1,1
ambient complexity	4
ambient feature size	0

RQ4

Visualizer 2 slider	4
ambient	on
trace level	10
ambient trace level	4
ambient precision	1,3
ambient complexity	5
ambient feature size	0

RQ5

Visualizer 2 slider	5
ambient	on
trace level	10
ambient trace level	4
ambient precision	1,5
ambient complexity	6
ambient feature size	0

RQ6

Visualizer 2 slider	6
ambient	on
trace level	10
ambient trace level	4
ambient precision	1,7
ambient complexity	7
ambient feature size	0

RQ7

Visualizer 2 slider	7
ambient	on
trace level	10
ambient trace level	4
ambient precision	1,9
ambient complexity	8
ambient feature size	0

RQ8

Visualizer 2 slider	8
ambient	on
trace level	10
ambient trace level	4
ambient precision	2,1
ambient complexity	9
ambient feature size	0

RQ9

Visualizer 2 slider	9
ambient	on
trace level	10
ambient trace level	4
ambient precision	2,3
ambient complexity	10
ambient feature size	0

RQ10

Visualizer 2 slider	10
ambient	on
trace level	10
ambient trace level	4
ambient precision	2,5
ambient complexity	11
ambient feature size	0

Assessment overview of VELUX Daylight Visualizer 2 for all settings

Table 8 gathers the essential information about the results of the assessment of VELUX Daylight Visualizer 2 against test cases 5.4, 5.5, 5.6, 5.7, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14 for all the settings.

Test Case number	Test Case variant	RQ0	RQ1	RQ2	RQ3	RQ4	RQ5	RQ6	RQ7	RQ8	RQ9	RQ10	Custom
Test Case 5.4	Roof opening 1 m x 1 m	3.68	1.38	1.22	0.92	0.84	0.77	0.75	0.71	0.66	0.67	0.69	0.75
	Roof opening 2 m x 2 m	0.75	0.14	0.29	0.05	0.09	0.05	0.05	0.03	0.01	0.02	0.03	0.04
	Roof opening 4 m x 4 m	0.21	0.25	0.02	0.17	0.14	0.16	0.14	0.14	0.17	0.16	0.15	0.18
	Wall opening 2 m x 1 m	1.88	0.32	0.07	0.21	0.32	0.39	0.42	0.45	0.44	0.76	0.46	0.41
	Wall opening 3 m x 2 m	1.49	0.84	0.62	0.62	0.53	0.49	0.48	0.45	0.47	0.46	0.46	0.49
	Wall opening 4 m x 3 m	0.10	0.14	0.33	0.27	0.33	0.34	0.37	0.38	0.36	0.38	0.39	0.36
Test Case 5.5	-	1.15	1.08	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07
Test Case 5.6	S_2 of 50 cm x 50 cm	32.38	11.66	6.64	3.57	2.35	2.87	2.09	1.93	0.99	1.29	1.39	3.28
	S_2 of 4 m x 4 m	0.96	0.70	0.45	0.45	0.44	0.39	0.38	0.39	0.37	0.36	0.36	0.38
	S_2 of 500 m x 500 m	3.88	3.07	2.42	2.36	2.10	2.11	1.91	1.99	1.98	1.87	1.87	2.00
Test Case 5.7	-	2.23	0.68	0.25	0.42	0.30	0.13	0.15	0.15	0.06	0.04	0.05	0.16
Test Case 5.9	Roof opening 1 m x 1 m	11.50	4.17	2.74	2.40	1.91	1.56	1.28	1.40	1.22	1.15	1.07	1.58
	Roof opening 4 m x 4 m	3.83	3.31	3.21	3.19	3.18	3.15	3.12	3.12	3.12	3.12	3.12	0.37
Test Case 5.10	Roof opening 1 m x 1 m	9.71	3.34	3.92	5.19	5.10	5.33	5.46	5.54	5.27	5.19	5.22	5.13
	Roof opening 4 m x 4 m	2.14	1.70	1.56	1.62	1.67	1.65	1.65	1.66	1.68	1.67	1.66	1.65
Test Case 5.11	Wall opening 2 m x 1 m	5.75	2.48	1.49	0.96	0.83	0.67	0.60	0.45	0.39	0.36	0.31	0.65
	Wall opening 4 m x 3 m	1.55	0.97	0.84	0.67	0.71	0.67	0.64	0.67	0.65	0.61	0.61	0.65
Test Case 5.12	Wall opening 2 m x 1 m	8.53	5.70	4.99	4.44	4.68	4.59	4.64	4.57	4.51	4.38	4.31	4.62
	Wall opening 4 m x 3 m	2.69	2.53	2.39	2.34	2.36	2.33	2.27	2.26	2.28	2.28	2.28	2.32
Test Case 5.13	2 m horizontal mask	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05	2.05
Test Case 5.14	6 m vertical mask	3.77	1.24	0.89	0.30	0.16	0.29	0.29	0.11	0.04	0.11	0.09	0.17
	9 m vertical mask	2.89	1.56	0.75	0.39	0.33	0.29	0.22	0.19	0.18	0.12	0.18	0.16
Minimum		0.10	0.14	0.02	0.05	0.09	0.05	0.05	0.03	0.01	0.02	0.03	0.04
Maximum		32.38	11.66	6.64	5.19	5.10	5.33	5.46	5.54	5.27	5.19	5.22	5.13
Average		4.69	2.24	1.74	1.53	1.43	1.42	1.36	1.35	1.27	1.28	1.26	1.29

Table 8: *Average error (in %) between the simulation results obtained with VELUX Daylight Visualizer 2 and the CIE 171:2006 analytical references, for each test case, each case variant, and each setting. The colour of the average error indicated whether the test is passed, based on the ENTPE – DGCB / CNRS expertise in lighting design. A green colour indicates the test case variant is passed for the corresponding VELUX Daylight Visualizer 2, and a red colour indicates that VELUX Daylight Visualizer 2 failed to simulate accurately the test case variant for the corresponding setting. Minimum, maximum, and average error for each RQ are also indicated.*

Conclusion about the assessment of VELUX Daylight Visualizer 2 against CIE 171:2006 test cases

For the following settings: RQ3, RQ4, RQ5, RQ6, RQ7, RQ8, RQ9, RQ10, custom, VELUX Daylight Visualizer 2 can predict accurately daylight levels and appearance of a space lightened with natural light, prior to realization of the building design.

Indeed, VELUX Daylight Visualizer 2 passed the CIE 171:2006 test cases dedicated to natural lighting for the following settings: RQ3, RQ4, RQ5, RQ6, RQ7, RQ8, RQ9, RQ10, custom.

For all these settings, VELUX Daylight Visualizer 2 simulates the following aspects of natural light transport with a maximal error lower than 5.54 % and an average error lower than 1.53 %:

- *Luminous flux conservation*
- *Directional transmittance of clear glass*
- *Light reflection over diffuse surfaces*
- *Diffuse reflection with internal obstructions*
- *Sky component for a roof unglazed opening for CIE sky types 1-15*
- *Sky component under a roof glazed opening for CIE sky types 1-15*
- *Sky component and external reflected component for a façade unglazed opening for CIE sky types 1-15*
- *Sky component and external reflected component for a façade glazed opening for CIE sky types 1-15*
- *Sky component and external reflected component for an unglazed façade opening with a continuous horizontal mask for CIE sky types 1-15*
- *Sky component and external reflected component for an unglazed façade opening with a continuous vertical mask for CIE sky types 1-15*

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