

# Application of the CIE test cases to assess the accuracy of lighting computer programs

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## Abstract

To answer to an increasing need in the lighting simulation domain, the CIE technical committee 3.33 defined recently a set of test cases to be used for assessing the accuracy of lighting computer programs. These test cases have the advantage of avoiding or reducing the uncertainties in the validation reference data by using simple analytical scenarios or by applying reliable experimental protocols.

This paper presents an application example of these test cases to two existing lighting computer programs. Thirty-two different testing scenarios were used covering different aspects of the lighting simulation domain: direct artificial lighting, direct daylighting and diffuse reflections and inter-reflections.

This work showed the usefulness of the CIE simple test cases in identifying the strengths and weaknesses of the tested programs and the accuracy and the capabilities of the programs in simulating different aspects of the lighting propagation were clearly verified. However, the need to expand the CIE set of test cases to other aspects of light and daylighting design has been noted.

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## 1. Introduction

The use of lighting computer programs is gaining in importance in the field of building design. Lighting programs can help designers or decision makers to choose appropriate architectural and/or technical solutions to achieve a comfortable built environment while reducing energy consumption for example through the substitution of daylight to electric light and a better use of the solar heat.

Within this context, an increasing number of lighting computer programs is proposed around the world. However, it is still difficult for the user to estimate the range of errors to be expected when using a particular program for a particular task. This is due to the lack of reliable and transparent validation studies.

A few years ago, the IEA SHC Task 21 conducted a valuable study in the domain of lighting programs validation, where a set

of experimental validation datasets were created and compared to a number of existing tools [1,2]. In a continuation of this work, and to broaden the domain of lighting propagation covered by these types of reliable datasets, a set of simple test cases has been defined or collected within the activities of the CIE Technical Committee 3.33 and Subtask C of the IEA SHC Task 31 [3,4].

These test cases were recently proposed within a draft CIE technical report [5], and therefore have the potential to become a unified reference for lighting programs validation, which would allow for transparent and objective comparisons between existing programs.

The objective of the present paper is to show an application example of the CIE set of test cases where two existing lighting programs are tested and compared.

## 2. CIE test cases and applied validation approach

The validation approach proposed through the CIE test cases is based on the concept of testing separately the different aspects of the lighting simulation. This allows assessing the domain of applicability of a tested program by highlighting its strength and weakness areas.

Therefore, simple test cases were defined, each involving a limited number of parameters and highlighting a given aspect of

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the lighting propagation and simulation domain. Proposed test cases are mainly based on theoretical scenarios with analytically calculated reference data, thus avoiding uncertainties. However, a set of experimental test cases is also proposed for artificial lighting, where the simplicity of the scenarios and the applied rigorous protocol limited the uncertainties in the reference values.

The proposed set of scenarios covers different aspects of the lighting propagation domain, including direct and indirect lighting calculations in both artificial lighting and daylighting. A complete description is given for each scenario including the geometry, the light source, the reference points, and the related reference data.

### 3. Tested programs

The programs used for the application example are Lightscape 3.2 and Relux Professional 2004. The first is a previously commercialized program and the second is a freeware supported by a number of luminaire manufacturers.

Lightscape is a lighting and visualization application that uses both radiosity and ray tracing algorithms where only the radiosity solution is considered for the quantitative results. The applied radiosity algorithm uses progressive refinement and adaptive meshing methods.

Both artificial lighting and daylighting can be simulated. For artificial lighting, point, linear or area sources can be used with intensity distribution files in IESNA or CIBSE formats. For daylighting, the program is supposed to simulate CIE overcast and clear skies in addition to an intermediate sky.

Geometry can be imported in DXF or DWG formats or can be created within the program by mean of simple surfaces.

Direct or global illuminance results can be obtained after the radiosity calculations at selected points or grid of points of any surface of the simulated geometry.

For this study, the parameters affecting the radiosity calculations were set as following: (Table 1)

Relux is also a radiosity-based program (point to point method) where both artificial lighting and daylighting simulations can be conducted. Luminaire photometry can be

Table 1  
Radiosity parameters settings for Lightscape 3.2 simulations

Group	Parameter	Value
Receiver	Mesh spacing, min	0.05 m
	Mesh spacing, max	0.5 m
	Subdivision contrast threshold	0.3
Source	Direct source, min	0.05
	Direct source, subdivision accuracy	1
	Indirect source, min	0.05
	Indirect source, subdivision accuracy	1
	Shadow grid size	Nine (9)
Process	Shadows	ON
	Daylight	ON
	Direct only	OFF
	Skylight accuracy	1
	Daylight through windows and openings only	OFF

Table 2  
Lighting calculation parameters for Relux 2004 simulations

Group	Parameter	Value
Precision	Only direct fraction or	ON
	High indirect fraction (for diffuse reflection tests)	ON
Raster	Raster spacing	0.05
	Dynamic raster	ON, fine

imported directly from manufacturers' integrated libraries or in IESNA or Eulumdat formats and luminaire dimensions can be set manually. Simulated sky conditions are CIE overcast and clear skies.

For interior lighting, simple geometries can be automatically generated based on room dimensions. Geometries that are more complex can be created by mean of blocks and surfaces or can be imported from AutoCAD through a dedicated plugin.

Illuminance values can be obtained at pre-selected reference planes for the direct only component or with indirect lighting.

The modeling accuracy parameters used for this study are as following: (Table 2)

### 4. Testing results

Below is presented a comparison between simulation results of tested programs and the reference data for 32 different testing scenarios of the CIE set of test cases.

A short description of each test case is given alongside the related results. A complete description of the test cases can be found in the CIE draft technical report [5].

We would like to note that the presented results were obtained by using the above listed set of modeling parameters. Therefore it is possible that the same programs would be capable of obtaining better or worse accuracy if different modeling parameters were used.

#### 4.1. Artificial direct lighting—point light sources

The objective of this test case is to assess the capability of software programs to calculate the direct illuminance under a point light source described by an intensity distribution file.

The analytical scenario is a horizontal surface (4 m × 4 m) with a point light source at 3 m heights above the surface center. Two different types of theoretical intensity distributions are used: diffuse or asymmetrical. The position of the reference points is described in Fig. 1. The reference values are obtained analytically by mean of the following equation:

$$E = I_{ox} \times \frac{\cos \theta}{d^2},$$

where:  $E$  is the direct illuminance at a given point X (lx);  $I_{ox}$  the intensity of the point light source O in the direction of the point X (cd);  $\theta$  the incidence angle of the light arriving to the point X from the source O (radians);  $d$  the distance between the light source and the point X (m)

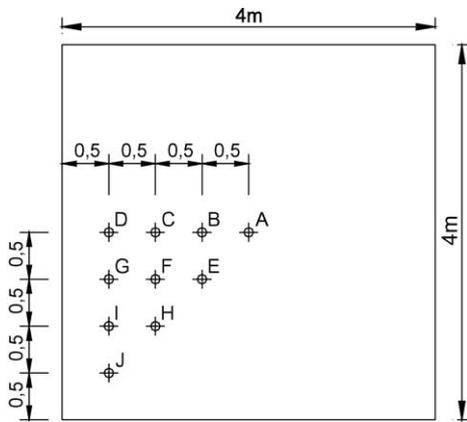


Fig. 1. Reference points' position for point light source scenario.

Results presented in Fig. 2 show excellent agreement between the two tested programs and the analytical reference for the diffuse intensity distribution: average and maximum errors are below 0.5% for both programs.

Similar results were also obtained for the asymmetrical distribution [6].

4.2. Artificial direct lighting—area light sources

The objective of this test case is to assess the capability of a lighting program to calculate the direct illuminance under an area light source. The importance of this test is related to the simulation of a luminaire of large dimensions compared to the distance between the measurement points and the luminaire (distance smaller than five times the dimension). In such cases, most of the lighting programs precede to the distribution of the luminous flux over the surface of the luminaire by mean of a grid of point light sources using the same intensity distribution.

The analytical scenario is a square room with a 1 m × 1 m light source at the center of the ceiling with a uniform intensity distribution (see Fig. 3). Two types of intensity distributions are used: diffuse and asymmetrical. The position of the reference points is described in Fig. 3. The reference values are obtained analytically by mean of the following equation:

$$E_1 = M_2 \times F_{12},$$

where:  $E_1$  is the direct illuminance at the point  $P_1$  received from the area light source  $S_2$  (lx);  $M_2$  the luminous exitance of the

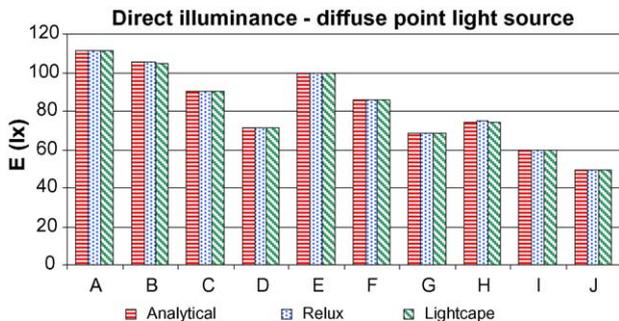


Fig. 2. Simulation results for point light source scenario with diffuse photometry.

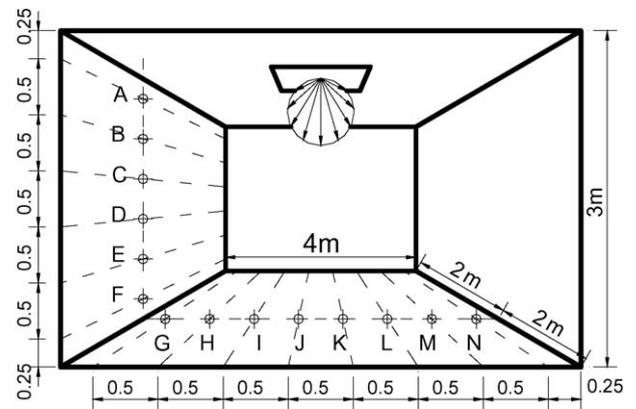


Fig. 3. Scenario description for area light source test case.

area light source  $S_2$  ( $\text{lm}/\text{m}^2$ );  $F_{12}$  the configuration factor between the receiving area  $dS_1$  (representing the measurement point  $P_1$ ) and the area light source  $S_2$ .

Same as for the point light source scenario, simulation results of both tested programs correlated well with the analytical reference (see Fig. 4). Average error for both programs is below 0.5%. The maximum error is an underestimation of 1.25% for Lightscape at points J and K (Fig. 4).

4.3. Artificial lighting—experimental reference data

The set of test cases presented in this section is the only one of this study using experimental reference data: it is based on the CIBSE Technical Memorandum TM 28/00, which describes a set of reliable experimental measurements for artificial lighting scenarios [7]. A rigorous experimental protocol was conducted to reduce interfering error sources and related uncertainties. The scenarios include a rectangular room (see Fig. 5) with six different combinations of surface reflectance and luminaire types. A complete description of the scenarios is given, including in particular the luminaires intensity distribution files in CIBSE TM 14 format, where each luminaire was photo-metered separately.

The reference data is presented by mean of the upper and lower tolerance bounds based on the estimated error sources in the measurements and in the scenario description (e.g. sensor cosine and color corrections, sensor calibration, lumen output

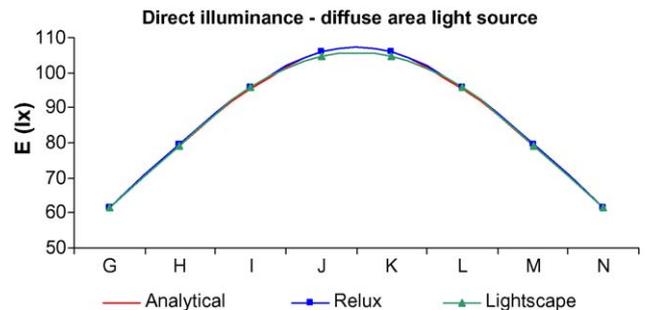


Fig. 4. Simulation results at floor reference points for area light source scenario with diffuse photometry.

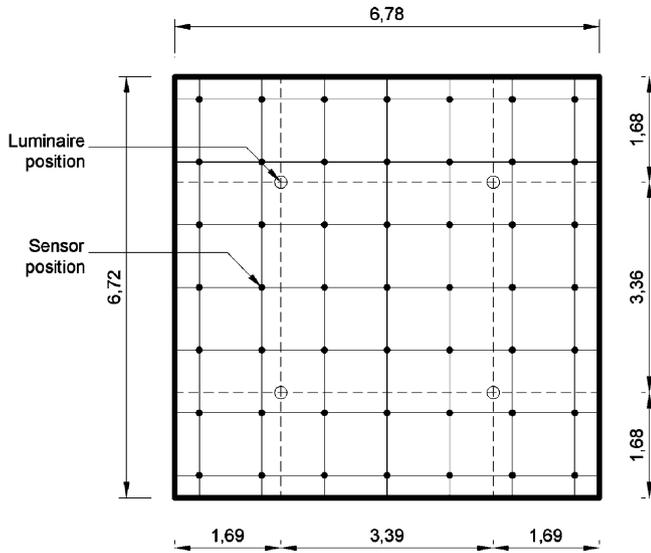


Fig. 5. Scenario description for artificial lighting experimental test cases.

fluctuation, luminaire position and flux output distribution, room dimensions, surface reflectance, etc.) [5,7]. The tolerance bounds have been defined [5,7] as  $\pm 2$  times the global error source ( $U = 10.5$ ) or a total of  $\pm 21\%$  which is obtained by mean of the following equation:

$$U = \sqrt{\sum_i (\text{Error}_{(i)})^2}$$

Figs. 6 and 7 present the results at one position of the reference points for two of the six testing scenarios and show a good agreement between the simulation results of the two tested programs and the experimental reference: calculated illuminances are within the tolerance margins and respects the profile of the measured values. However, it is noted that the simulation results are closer to the lower boundary for the direct lighting scenarios (black walls) and to the upper boundary for indirect lighting scenarios (gray walls).

Similar results were obtained for the four other scenarios and at all reference positions [4,6].

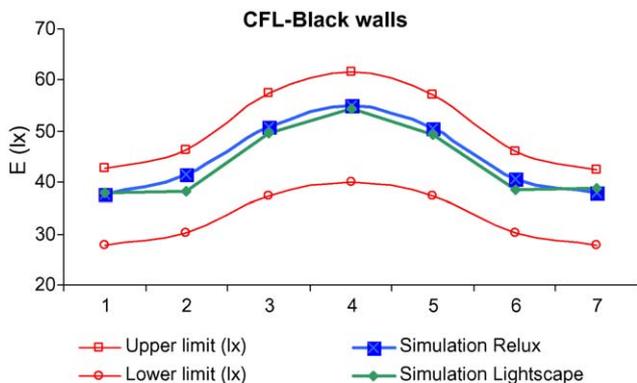


Fig. 6. Simulation results for compact fluorescent lamps and black walls at reference point's position 4.

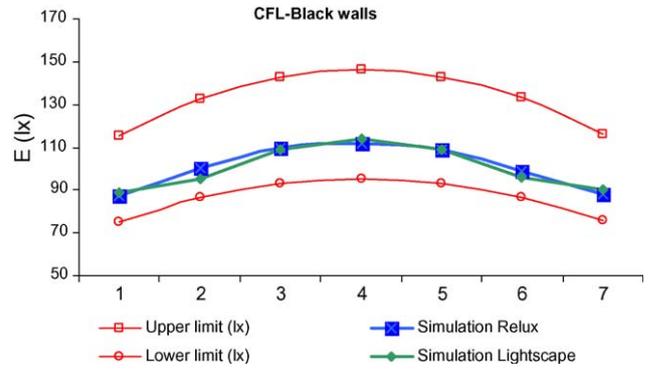


Fig. 7. Simulation results for compact fluorescent lamps and gray walls at reference point's position 4.

#### 4.4. Daylighting—luminous flux conservation

This test case aims to assess the flux conservation in a daylight simulation between an external luminance field and the internal space through an unglazed aperture. The importance of this test is related to the error that can be introduced into daylighting simulation results if this flux conservation is not respected. The analytical reference solution supposes that 100% of the flux arriving at the aperture's external surface should be conserved and received as direct illuminance on the internal surfaces. The geometry used for this test is a black room (0% reflectance) of  $4\text{ m} \times 4\text{ m} \times 3\text{ m}$  with a roof opening ( $1\text{ m} \times 1\text{ m}$ ) or a façade opening ( $2\text{ m} \times 1\text{ m}$ ).

The simulation results for this test case (see Fig. 8) show a good flux conservation with Relux, but a considerable error with Lightscape: a loss of 16% in the transferred luminous flux is observed for the roof opening scenario and an overestimation of 14% is observed for the façade opening scenario.

#### 4.5. Directional transmittance of clear glass

This test case aims to assess the capability of a program to take into consideration the directional transmission of normal glass (with negligible bi-directional effects). The importance of this test is related to the influence that a glazing material can have on daylight availability inside a building.

The scenario includes a black room with an external directional source aimed at the center of a roof opening. The total direct illuminance inside the room is calculated with and

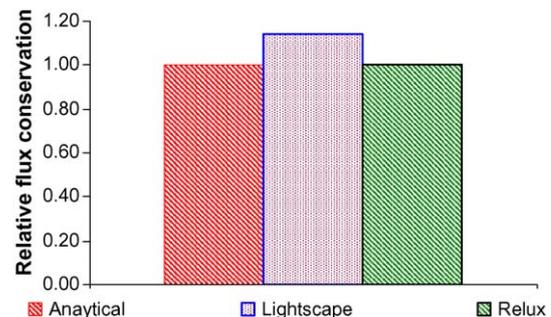


Fig. 8. Simulation results for flux conservation test case with a façade opening.

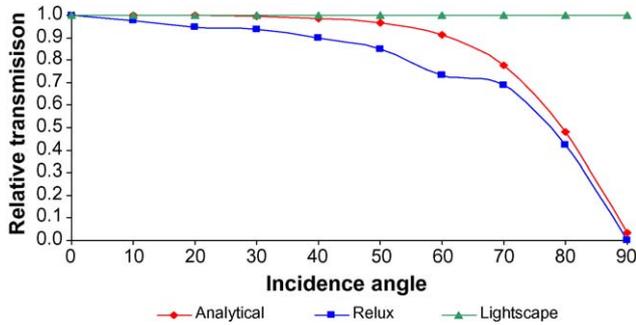


Fig. 9. Simulation results for the directional transmission test case.

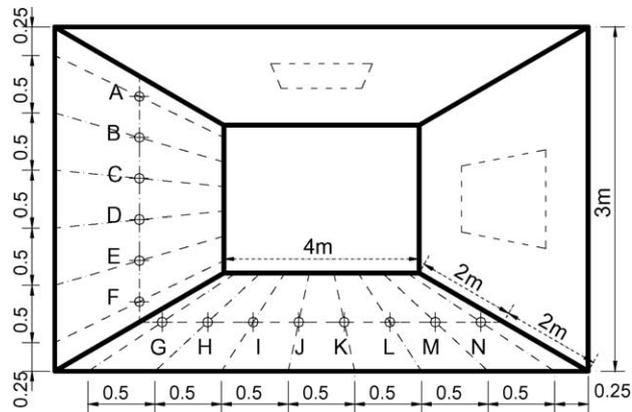
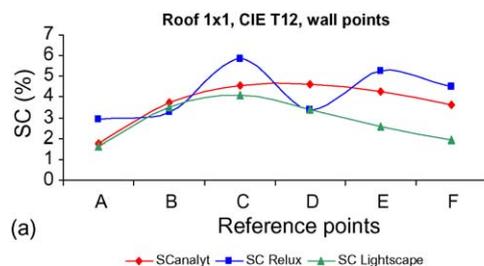


Fig. 10. Geometry description and reference points' position for direct daylighting tests.

without a glazing on the aperture surface, for different incidence angles of the light source. This allows the simulated directional transmission of the glazing material to be obtained.

The reference solution can be any analytical or experimental curve of the directional transmission of any normal glazing type, as long as the tested program is intended to simulate such a type.

Fig. 9 presents the results of the two tested programs, compared to the analytical solution defined by Mitalas and Arseneault for 6 mm thick clear glass [8]. It shows that Lightscape does not take into consideration the directional transmission of glass. Relux accounts for the angular transmission effect but the results do not correlate well with the analytical solution, where an underestimation of the transmission is generally observed.



#### 4.6. Direct daylighting—unglazed opening

This test case aims to assess the capability of a lighting program to simulate the contribution of the sky luminance distribution to the direct illuminance inside a room. CIE general sky types 12 (Clear, with sun position South at 60° elevation) and 16 (Overcast) are used to describe the luminance distribution. The geometry is a room of 4 m × 4 m × 3 m with a roof or a façade opening of varying dimensions (see Fig. 10). The thickness of the aperture is not taken into consideration. The opening is unglazed in order to avoid an error source related to the directional transmission of the glass. The internal surfaces are modeled to have 0% reflectance in order to avoid an error source related to inter-reflections, therefore the only the sky component (SC) of the daylight factor is used for the reference values. The reference data for Sections 4.6–4.8 is calculated with a computer program developed for this purpose (Skylux), and validated through comparison with the existing analytical solutions for uniform and CIE overcast skies [5].

Results presented in Fig. 11 (b) for a 1 m × 1 m roof opening show that Lightscape predicts a symmetrical illuminance distribution on the floor, which does not account for the directionality of the sky luminance distribution. However, in Fig. 11(a) Lightscape respects this directionality between the North and the South walls where a clear difference is obtained in the average illuminance values [4], but without a good agreement in the absolute values at the North wall reference points.

Relux results (with 1 m × 1 m roof opening) show a good agreement with the analytical reference for the floor points but not for the wall points.

However, for a roof opening of 4 m × 4 m, Relux results show a much better agreement for both floor and wall points as shown in Fig. 12 while the Lightscape agreement is much worse. Similar differences are observed for the roof opening with a CIE overcast sky.

Other results with façade openings (2 m × 1 m or 4 m × 3 m) and with CIE overcast sky leads generally to similar observations where very good agreements are observed for Relux and rarely for Lightscape [3,4,6].

#### 4.7. Direct daylighting—glazed opening

This test case aims to assess the capability of a program to simulate the influence of a glazing on daylight entry under a

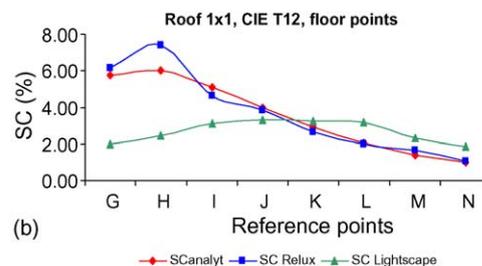


Fig. 11. Simulation results in SC for 1 m × 1 m roof unglazed opening and a CIE clear sky (General sky Type 12). (a) Shows results at wall reference points and (b) shows results at floor reference points.

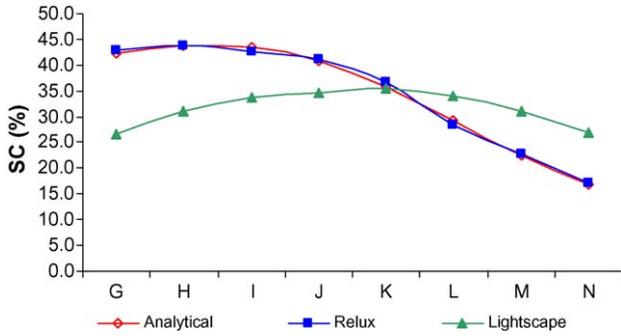


Fig. 12. Simulation results at floor reference points in SC for 4 m x 4 m roof unglazed opening and a CIE clear sky (General sky Type 12).

given sky luminance distribution. It combines the aspects treated in the scenarios of Sections 4.5 and 4.6.

The geometry used is the same as for test 4.6, in addition to a 6 mm thick clear glass over the opening surface.

Results are generally similar to those observed for the unglazed opening scenarios with an additional error source related to the directional transmission of the glass as it could be expected based on the Section 4.5 results [6].

The unexpected difference was for the 1 m x 1 m roof opening scenarios where Relux showed better results than those obtained for the unglazed opening (see Fig. 13). This difference is discussed in the results analyses presented in Section 5.

4.8. Direct daylighting with external mask

The objective of this test case is to verify the capability of a lighting program to simulate the influence of an external

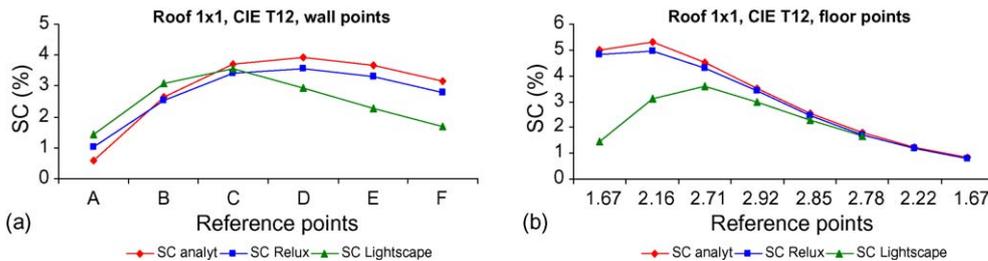


Fig. 13. Simulation results in SC for 1 m x 1 m roof glazed opening and a CIE clear sky (General sky Type 12). (a) Shows results at wall reference points and (b) shows results at floor reference points.

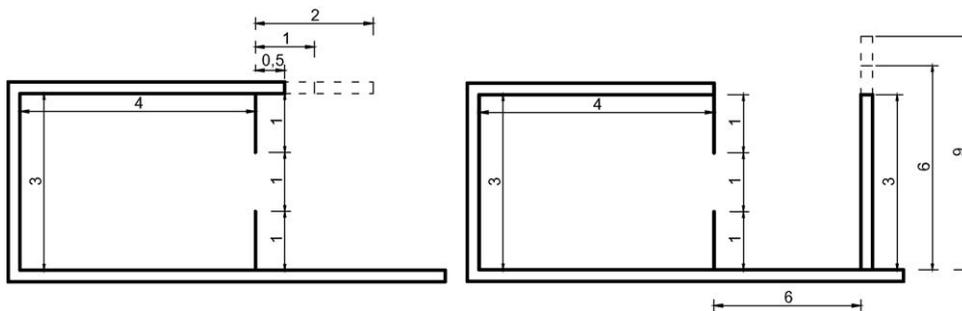


Fig. 14. Geometry description for the external mask scenarios.

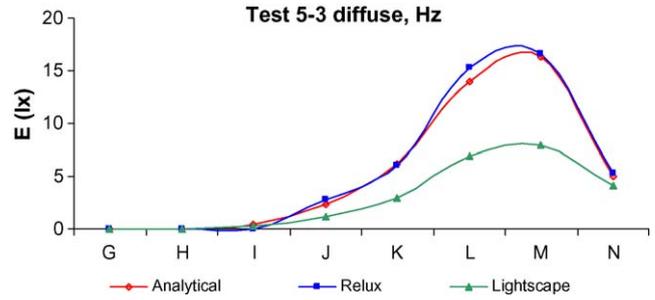


Fig. 15. Simulation results for the 6 m external vertical mask and a CIE clear sky.

shading mask on the internal direct illuminance. Actually, external masks can influence considerably the internal illuminance distribution inside a building.

The geometry used for this test case is a rectangular room of 4 m x 4 m x 3 m with a façade opening of 2 m x 1 m at 1 m above the floor. The wall thickness is not taken into consideration. No glass materials are used. Two types of external masks were considered: horizontal and vertical masks with different dimensions (see Fig. 14).

For this study, the reflectance of the masks was not taken into consideration, therefore only the obstruction effect was assessed, and only the sky component was considered in the reference results.

Results presented in Fig. 15 show that the obstruction effect of the external 6 m vertical mask is taken into consideration in both programs with an acceptable accuracy. The difference between Lightscape results and the analytical reference is related to the sky and not to the obstruction. Similar results are

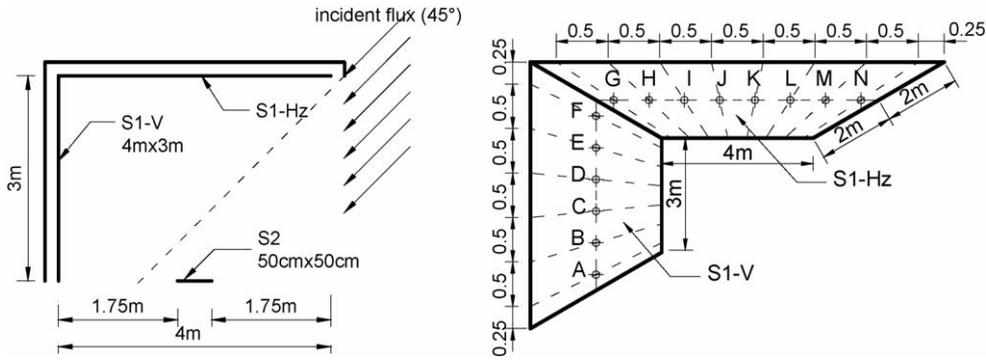


Fig. 16. Test case description for 50 cm × 50 cm diffusing surface ( $S_2$ ) and measurement points' position.

observed for other scenarios with different mask types and dimensions [4,6].

4.9. Indirect lighting—diffuse reflection

The objective of this test case is to assess the accuracy of a tested program in computing the light reflection over diffuse surfaces. The importance of this test is related to the light inter-reflections inside a room, but also to the reflection of daylight on the external ground and masks. The testing scenario includes a diffusing surface ( $S_2$ ) receiving uniform illuminance from a directional light source and diffusing a part of the unabsorbed flux toward two receiving surfaces ( $S_1$ -V and  $S_1$ -Hz) (see Fig. 16). The reference data is given at the measurement points of the receiving surfaces (shown in Fig. 16) in percentage of the direct illuminance at  $S_2$  ( $E_2$ ) multiplied by the reflectance of  $S_2$  ( $\rho S_2$ ). This percentage is equal to the form factor ( $F_{12}$ ) between the receiving elementary surface  $dS_1$  and the diffuse surface  $S_2$ . The indirect illuminance ( $E_i$ ) at a given point of the receiving surfaces can be given by the following equation:

$$E_i = F_{12} \times E_2 \times \rho S_2,$$

Three different scenarios are proposed with different sizes and positions of  $S_2$  (Fig. 16).

Results comparison presented in Fig. 17 show a very good agreement between the simulation results of the two tested programs and the analytical reference for a 50 cm × 50 cm diffusing surface ( $S_2$ ). Similar results were observed for the other scenarios [4,6].

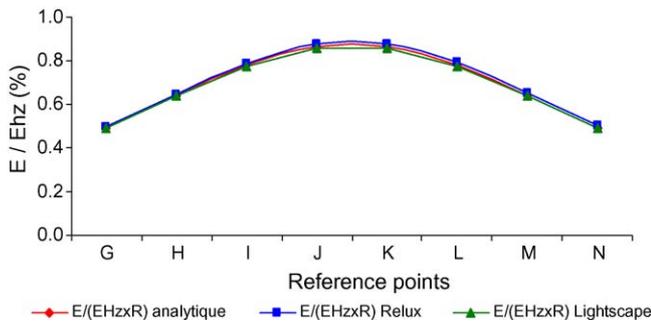


Fig. 17. Simulation results at  $S_1$ -Hz for diffuse reflection scenario with 50 cm × 50 cm diffuse surface.

4.10. Indirect lighting—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 a diffuse reflection. The importance of this test is related to the masking influence of internal furniture or to the external reflected component received from external masks through apertures. The testing scenario is described in Fig. 18 where  $S_2$  is the diffusing surface receiving uniform illuminance.

The simulation results of this test case (see Fig. 19) show that the two tested programs predicted accurately the influence of the obstruction on the diffuse reflection.

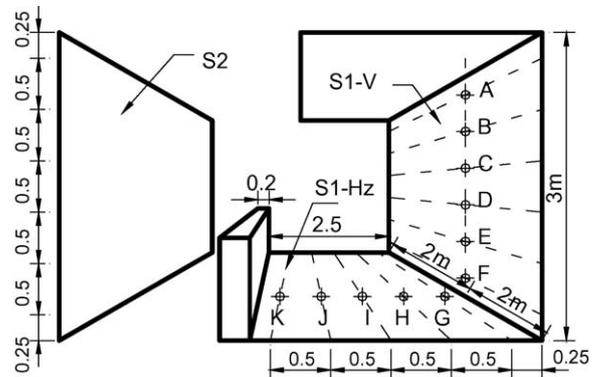


Fig. 18. Scenario description for diffuse reflection with obstruction.

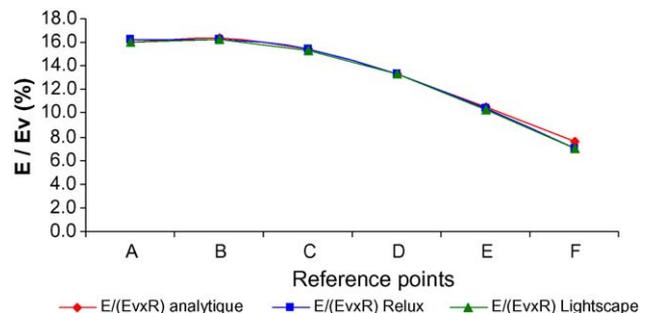


Fig. 19. Simulation results at  $S_1$ -V for diffuse reflection with obstruction.

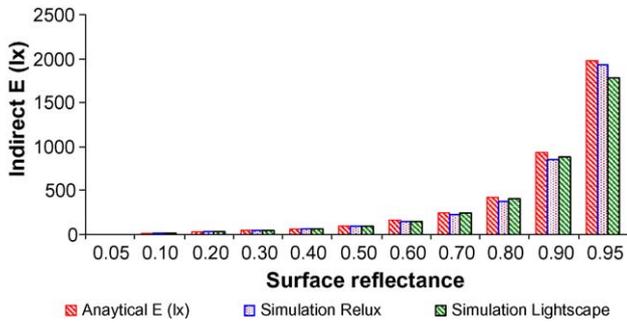


Fig. 20. Simulation results for the diffuse inter-reflections test case.

#### 4.11. Indirect lighting—diffuse inter-reflections

This test case aims to assess the variation of internal indirect illuminance with the average reflectance of internal surfaces. The importance of this test is related to the contribution of indirect lighting to the global illuminance inside a room.

The scenario includes a simple cubic room of 4 m × 4 m × 4 m with one isotropic point light source of known luminous flux ( $\phi = 10,000$  lm) at the center of the room. The surface reflectance ( $\rho$ ) varies from 0 to 95%. The reference values are obtained analytically by mean of the following equation:

$$E_{ir} = \frac{1}{S_T} \times \frac{\rho\phi}{1 - \rho},$$

where:  $E_{ir}$  is the room average indirect illuminance (in lx);  $S_T$  the room total surface (in m<sup>2</sup>).

The simulation results shown in Fig. 20 prove the capability of the tested programs to handle the inter-reflections inside a rectangular room. A slight underestimation is observed for high reflectance values (above 0.7) with a maximum error with Lightscape for the reflectance of 0.95. However, it should be noted that such high reflectance values are rarely present in real world scenarios.

## 5. Results analyses

The comparison between the simulation results of the two tested programs and the reference data of the CIE test cases highlighted the capabilities and limits of these programs with regards to the lighting simulation aspects covered by the CIE test cases.

Analyses of these results is presented below, however the following remarks should be noted:

- The results presented in this study were obtained by using a given set of parameters settings for the programs, and observed accuracy might not be guaranteed for lower parameters.
- The test cases used for this study covers limited number of lighting simulation aspects, and the observed accuracy should not be generalized to other untested aspects like for example the spectral and bi-directional transmission or reflection effects of materials.

### 5.1. Validity of Lightscape 3.2 in lighting simulations:

The analyses of Lightscape results can be summarized as following based on these tests:

#### A. Strength points

- High accuracy in diffuse reflections and inter-reflections.
- High accuracy in artificial lighting simulations.

#### B. Weakness points

- Inaccuracy in daylighting flux conservation.
- Inaccuracy in Sky Component calculations.
- Incapable of simulating the directional transmission of glass.

Therefore, the program can be recommended for artificial lighting calculations. However, it should be used with prudence in daylighting calculations, taking into consideration its tendency to underestimate or overestimate the direct illuminance with a roof or a façade opening, and its limitation in simulating the directional transmission of glass materials.

### 5.2. Validity of Relux Professional 2004 in lighting simulations:

The simulation results of Relux were generally satisfactory showing high accuracy in the different tested aspects.

The lowest accuracy was observed for the glass directional transmission where results did not correlate perfectly with the analytical reference. Nevertheless, the daylighting results with the glazed openings showed that the observed difference in the directional transmission has a limited effect on the accuracy of calculated illuminances inside the room.

The other case where Relux showed a lower accuracy is for the 1 m × 1 m unglazed roof opening. However, it was noted that the program accuracy is very high for the same scenarios but with glazed openings. The only other difference between the two sets of scenarios is the way the geometry was defined in the program. For the glazed openings, the room geometry was modeled by the program by means of its dimensions defined within the interface dedicated to interior projects. For the unglazed opening, the geometry had to be imported into an exterior project scene by mean of it's surfaces because the integrated interior modeling system does not allow to define unglazed openings. The unexpected differences in the results can therefore be explained by a difference in the applied calculation procedure between the two types of 3D models.

Another observation that could be made following to this study is related to the influence of the size of the default surface of an exterior project on the sky meshing and therefore on the accuracy of the daylighting calculations. Actually, when starting an exterior project, the program automatically creates a default surface that can be resized by the user. It was observed that the accuracy of the program in daylighting scenarios decreases dramatically with smaller dimensions of this surface. We inferred that the accuracy of the sky dome meshing varies with the size of the default exterior surface, and this was confirmed afterward by the program developers. Nevertheless,

this verification allowed the developer to avoid this problem in the latest version of the program.

## 6. Conclusions

This study presented a concrete application example of the CIE test cases defined to assess the accuracy of lighting computer programs.

Due to their simplicity, the usefulness of these test cases was proven in highlighting the strength and weakness areas of the tested programs and therefore in defining the domain of applicability of these programs. Testing results allowed us to form conclusions regarding the capability of the programs to accurately simulate, or not, the different lighting propagation aspects highlighted separately in the different test cases. Such verifications are useful for both program developers who can identify and fix unexpected bugs and for users interested to know more about a program they are using or intend to use.

The usefulness of the proposed test cases was also proven in making objective comparisons between programs based on reliable and unified reference data.

This study showed also the usefulness of combining the CIE simple test cases with parametric studies to optimize program parameters settings according to desired accuracy and calculation time.

However, to make better use of the CIE test cases, some recommendations can be drawn from the present work:

- The CIE set of test cases should be completed with new test cases covering other aspects of lighting propagation like, for

example, the spectral and bi-directional effects of building and glazing materials and the influence of interior obstructing surfaces and exterior environmental conditions.

- Dissemination should be made for the proposed test cases and for results from tested programs through a reliable independent body to make them transparently accessible for program users and developers. A dedicated website controlled by the CIE or the IEA can be a suitable solution.

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