SIMULATION OF CLEAR, CLOUDY AND INTERMEDIATE SKIES BY LIGHTSCAPE: RESULTS OF TESTS

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ABSTRACT

In this paper we present a procedure to test software ability to describe daylight sources. The method will be applied to Lightscape release 3.2 [1]. The results have been achieved independently from the software developers comparing software results with analytical solutions.
The tests deal with: a) definition of the algorithms used to represents different skies; b) influence of sun position; c) ground reflection management. Finally suggestions on how to use Lightscape in your daylight design are given.

KEYWORDS

Lightscape, daylight, validation, sky model

INTRODUCTION

Nowadays architects freely built articulated shapes that lightly stands in the air. In order to design such buildings, it is necessary to be supported by design tools (scale models, automatic calculation routines for structural stresses, CAD programs, energy consumption software…). This is true also in lighting design. The building appears to people because light casts shadows on it, that's why it is important to forecast both daylight and artificial light interaction with the building. In this paper, we will deal with daylight simulation. In daylighting design, project tools can help in choosing alternative shapes and materials, evaluating screens and shading devices, controlling energy consumption, designing artificial light as a complement to daylight.
Design tools can be scale models in artificial skies or lighting software. Artificial skies are a scarce resource, requiring the construction of several scale models, one for each configuration to be tested. Software are quick in calculation and can usually run on office computers and, thanks to their realistic rendering, they make the communication easier with the designers' clients.

TESTED TOOL

We will present a test procedure for the evaluation of daylight sources in software programs and apply it to Lightscape, dealing with release 3.2. This software has been chosen because it is cheap, user-friendly and equipped of an interface helping in importing geometries from several CAD software. Moreover, as it produces both a quantitative (illuminance and

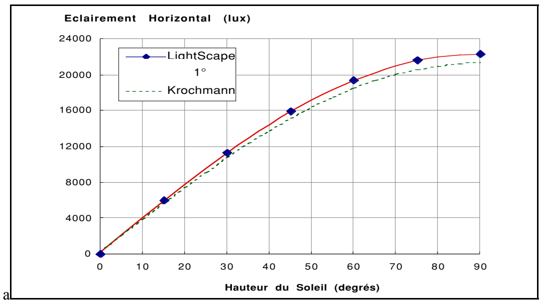
luminance) and qualitative (realistic rendering) output, it is one of the most often used in architectural context.
Lightscape offers the following capability to simulate daylight: a) possibility to freely choose the geometry and the location of the simulation subject; b) possibility to model sun position at any site; c) clear, cloudy and intermediate sky representation; d) possibility to fix the level of accuracy in daylight calculation.
Direct daylight is reproduced throughout a directional source, representing the sun, while a luminance distribution is used for skylight. The illuminances due to daylight sources will be analytically calculated for simple configurations and the obtained results compared to those produced by Lightscape for the same scenes. The reported results have been achieved independently from the software developers comparing software results with analytical solutions.

DAYLIGHT SIMULATION

Lightscape equations of skies: clear, cloudy, intermadiate

In order to simplify the representation of change in daylight levels and distribution, software use algorithms based on standardised luminance distributions. All daylight simulation programs take into consideration simplified luminance distributions describing sky dynamism, some distributions are standardised by CIE (Commission Internationale pour l'Eclairage) and IESNA (International Engineering Society of North America). Unfortunately some firms don't inform users about the sky's equations used.
Using daylight calculation in Lightscape you can choose among 3 different skies: a) cloudy sky, b) intermediate sky, c) clear sky. Unfortunately uniform sky, often used in order to compare different software or configurations, is not available; moreover Lightscape does not give the possibility to simulate any other sky luminance distributions.
Lightscape's equations for clear, cloudy and intermediate sky equations have been evaluated through a parametric work developed by the LASH's Lighting Group [2]. The luminance distribution of a determined sky is always expressed as a function of zenithal luminance. In order to know luminance absolute values, there is the need of an equation connecting zenithal luminance or horizontal illuminance with solar altitude. This is what was used to find out Lightscape sky model equation. A black cube with external walls perpendicular to cardinal directions on a black external ground has been modelled, then Lightscape simulations of direct lighting for clear, cloudy and intermediate sky run, the sun was put at south and solar altitude moved from 0 until 90°, every 15°. The illuminances on the cube surfaces were collected [3]. Then, resulting illuminances for the same conditions and orientations were calculated for CIE and IESNA sky models. IESNA/CIE values were compared with the ones provideded by Lightscape. It is important to underline that these are not the only models existing, neither the only used (for example Radiance uses CIE clear and cloudy sky models, but Matsumara intermediate luminance distribution [4]), so it can be necessary to calculate other standard sky illuminances to find out the sky model used by the software. For further information on sky models, specific literature should be consulted [5], [6], [7], [8], [9], [10], [11].
In order to formulate sky model equation the function of the illuminance horizontal dependence from the solar altitude has to be found, then luminance distribution should be hypothesised and verified from vertical illuminance changes due to solar altitude [2].
When simulating cloudy sky conditions (Figure 1), horizontal values almost double vertical ones at each solar altitude (Figure 1b), this is true both for IESNA and CIE model. The

difference in the absolute figures grows up with solar altitude reaching a maximum of 2% (Figure 1a). Lightscape results correspond to the IESNA equation.



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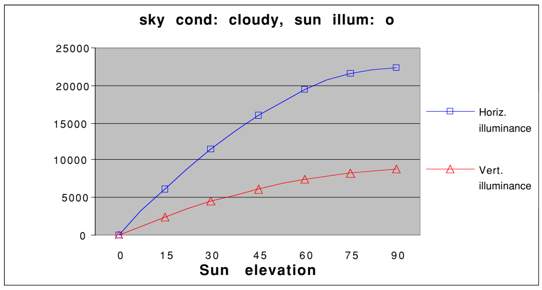

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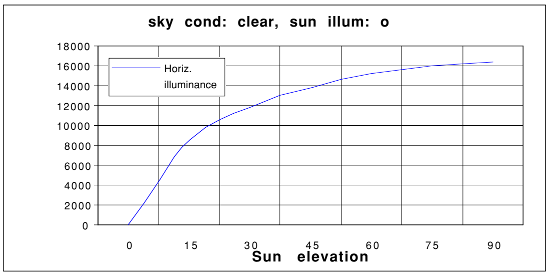
Figure 1 Cloudy sky, on left (a), comparison between CIE and IESNA horizontal values, on the right (b), the Lightscape/IESNA [2]

When simulating clear sky conditions, the IESNA model corresponds to CIE's [9]. In this case vertical illuminances grow rapidly till 30° of solar altitude, then decrease, reaching horizontal values, in exponential growth, at 45° (Figure 2). Lightscape follows this sky model.



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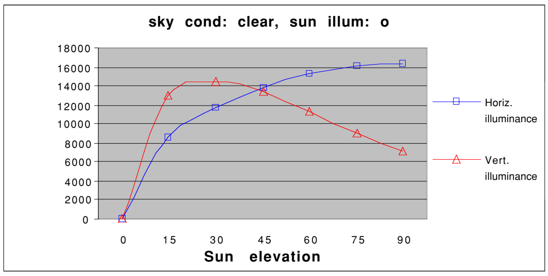

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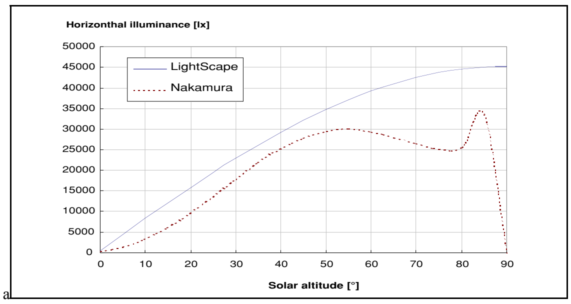
Figure 2 Clear sky, on left (a), comparison between CIE and IESNA horizontal values, on the right (b), the Lightscape/IESNA [2]

The IESNA intermediate sky model is characterised by a constant growth of horizontal illuminances (Figure 3a), which correspond to vertical illuminances till 30°. When solar altitude is between 30 and 45° vertical illuminances continue to increase, but then decrease (Figure 3b). Several models for intermediate skies exist. We decided to select the one developed by Nakamura [10], because it is used in the generaral sky model developed by Perez [11]. This model cannot be used in tropical area, as it does not deal correctly with high solar altitude. In Figure 3a it is possible to compare the IESNA with the CIE model. Till 45° of solar altitude, the difference between the two models is of about 15% and after it increases strongly. Lightscape follows the IESNA model, which can be applied for any geographical site.



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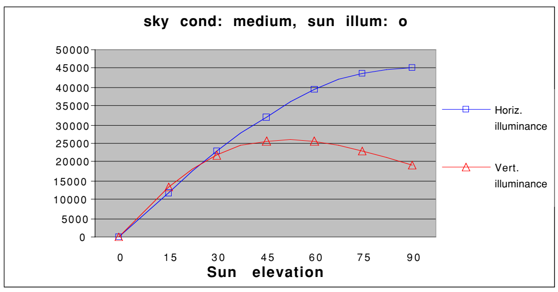

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Figure 3 Intermediate sky, on left (a), comparison between CIE and IESNA horizontal values, on the right (b), the Lightscape/IESNA [2] [3]

A private mailing with Lightscape authors confirms that the software uses the IESNA procedures, based on IES Report 'Calculation of daylight availability' [5], [6].

The procedure verifies the ability of a software to model daylight. It is possible to shows that the differences between standard sky models are sometimes important (Figure 3b), what can explain sometimes the differences between software results. That's why the first requirement for a daylighting software is to have a uniform sky model as it can be a common reference for different software. Lightscape does not simulate uniform sky.

Daylighting simulation options. Uniform sky simulation

In this paper indoor lighting will not be investigated, but there is one specific daylighting simulation option that affects the light so to overcome, in specific condition, to Lightscape lack of uniform sky. This option is «*Daylight through windows and openings only ».* It has the advantage of avoiding light trespass from geometry edges. The disadvantage is that the daylight distribution is taken into account only in exteriors, while the opening surfaces are automatically transformed in diffusive surfaces.
In order to simulate the light of a uniform sky incoming in a room, sometimes it is possible to use the option: « *Daylight through windows and openings only »* openings associated with sun illuminance at 0; the sky type is not important as the light incident on the opening is diffused indoor. We can show this trough a simple test.
Conditions: cloudy sky, solar altitude 90°, sun illuminance 0, surfaces reflectance 0%.
<u>Case a. Window</u>. The geometry is a rectangular room long two times its other dimensions, without one of the square surfaces.
The option « *Daylight through windows and openings only »* gives the effect of a diffusing window. In this case, the option does not simulate a uniform sky as the light seems to come in an equal way from every direction (from the ground as from the sky), while in reality only half of the sky is seen from a window. Under a uniform sky, in a room without a wall, ceiling should be lit almost only by reflected light (which in this case should not exist: surface reflectance=0), in Fig. 4 it is possible to notice that floor and ceiling have the same illuminance. In this case the option simulate a diffusive glass , but not a uniform sky.

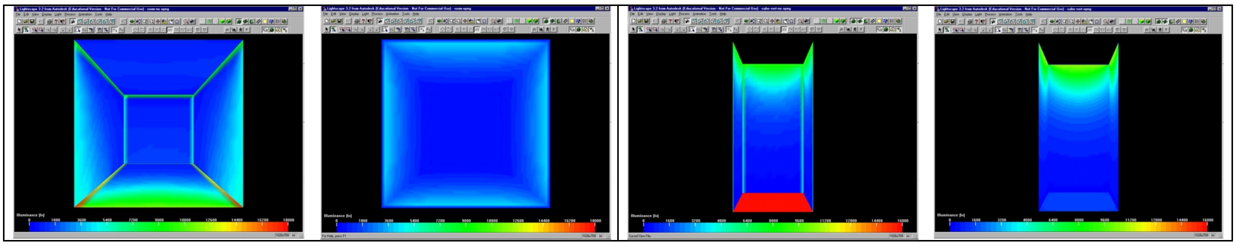

Figure 4: Window case, Option off (on the left), Option on (on the right), Skylight case, Option off (on the left), Option on (on the right) [3]

<u>Case b. Skylight</u>. The geometry is a rectangular room high two times its other dimensions, without the top square surface.
We can notice how light distribution is different in the two cases, on the left, with the option disabled, illuminance on floor level is stronger, while in the second case the illuminance close to the skylight is more important [3]. In this case the diffusive glass filtering the light of the cloudy sky simulates a uniform sky (Figure 4).

Sky definition accuracy

After the comprehension of sky model definitions, the attention has been focused on the sky definition accuracy. Lightscape setting parameters give the possibility to control the accuracy of sky simulation.

Actually the sky is divided in meshes, the size of these depends on the accuracy set and a bigger amount of meshes asks for a longer calculation time and a larger amount of memory.
In order to afford the empirical validation, it has been necessary to use a shoe box. Its characteristics are a square base with the edge 3 times the height, black surfaces (RL=0.05%), a square skylight in the centre of the roof with the edge half time the base. Sky accuracy varies in a range from 0 to 1. The simulation has been made for sky accuracy's steps of 0.1 for different sky conditions.
With the option 'daylight through windows and openings only' on, the results for every step of sky accuracy are always the same, i.e. the number of meshes does not affect the results of the simulation.
With the option 'daylight through windows and openings only' off, we notice, for example, that, with an accuracy of 0.7, the differences from the best accuracy simulation can reach 23% under cloudy sky conditions. The light is underestimated if the calculation doesn't run at the top accuracy. In the case of clear and intermediate luminance distribution the option 'daylight through windows and openings only' should not be used as light directionality becomes important and results are similar to the one referred to cloudy sky.
In conclusion it is necessary to use a high level of accuracy, even for preliminary test, accuracy higher then 85% is suitable, unless 'diffuse glass' or 'uniform sky' is simulated.

The sun as a light source

The principal source of daylight is sun. The rotation of the Earth about its axis, as well as its revolution about the sun, produces an apparent motion of the sun with respect to any point on the Earth surface. The position of the sun is expressed in term of two points: the solar altitude γ_s, which is the vertical angle of the sun above the horizon, and the solar azimuth ϑ_s, which is the horizontal angle of the sun from the south in the northern hemisphere [6].
In order to evaluate how Lightscape takes into consideration direct light sources we planned a test with spot light moving with steps of 15° on a quarter of circle around 2 black surfaces, an horizontal and a vertical one. In this way it was possible to evaluate how every directional source is taken into consideration by the software:

$$E_{horizontal} = k * \sin\gamma_s \cos\vartheta_s \text{ [lx]} \quad E_{vertical} = k * \cos\gamma_s \cos(\vartheta_s - \vartheta_{surface}) \text{ [lx]}$$

k = constant; γ_s : solar altitude [°]; ϑ_s: horizontal angle of the sun from due south in the northern hemisphere
This equation is correct and takes into consideration both fundamental parameters γ_s and ϑ_s.

GROUND REFLECTION

An other important point to develop is the way in which Lightscape models indirect illumination, i.e. reflection from the ground. Software programs mainly suppose a virtual ground of uniform luminance, while in Lightscape a real surface has to be modelled in order to simulate it. Following the assumption of Lambertian surfaces, implicit in radiosity algorithm, used by this software, it is possible to assume that the equation for the ground's contribution depends both on sky and sun [6].
A black cube with external walls perpendicular to cardinal directions on an external ground of variable reflectance (from 0 to 100 with steps of 10%) has been modelled, then Lightscape simulations of direct lighting for cloudy sky run. The illuminances on the surfaces were collected. Then, resulting illuminances for the same conditions and orientations were calculated analytically [6]. From the comparison between analytic and software results it is possible to say that the analytic law is not perfectly followed: illuminance differences goes from 2% (ρ =10%) to 13% (ρ =70%).

Usually the indirect light contribution is overestimated, while, in the case of high reflectance surfaces, the reflected light is underestimated.

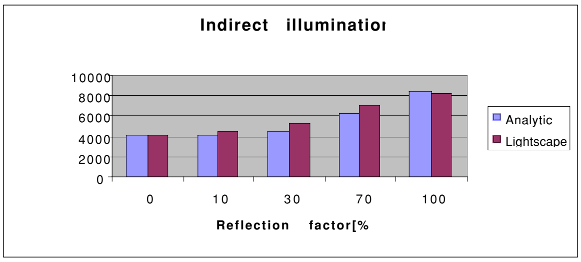

Figure 5 Indirect illumination comparison

CONCLUSIONS

In this paper a procedure to verify the ability of a software to model daylight was presented and applied to Lightscape. The information deriving from the tests are the following:

- The accuracy of the program is 'reasonably' good for assessing daylight availability
- Lightscape simulation of daylight sources is coherent with the IESNA procedure
- Uniform sky luminance distribution can be simulated only in rooms with zenithal lighting
- Any other sky model cannot be simulated with this software
- When the directional effect of the natural light source is important, the option “daylight through windows and openings only” has to be turned off
- Lightscape can be used for preliminary studies of daily and seasonal daylight variations
- Attention must be used if surfaces are reflective as indirect light is usually overestimated, unless in the case of high reflectance surfaces.

We have to underline that, results are sensitive to inputs and that crucial information are:

- The exact luminance distribution outdoor (accuracy in sky definition should be high),
- The exact behaviour of surfaces regarding their ability to reflect and diffuse light

Some of the main improvements needed by the software are the addition of the uniform sky and of the possibility to enter real sky luminance distributions.

Resuming: Lightscape has good potentials to be a reliable daylighting software among others, but for better performance there are some improvements to be done specially in the sky descriptions and the analysis output.

Further studies to investigate the reliability of indoor daylight simulation will follow.

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