COMPUTER TOOL TO AID NATURAL AND ARTIFICIAL LIGHT INTEGRATION IN BUILDING DESIGN

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ABSTRACT

This paper presents a computer application which applies methods for detailed daylighting and electric lighting numerical simulation, allowing interior illumination levels assessment. For the natural light, vertical windows are considered. For the artificial light, illumination levels can be calculated for a great variety of commercial fixtures, considering their luminous distribution curves. The performance of the integrated design is calculated in an hourly basis and represents the achieved energy savings if automatic (sensor-based) electric light control is used. All the calculations can be carried out in a very fast way, allowing the optimization of the electric light system and helping lighting designers in the adoption of such calculations in their everyday practice. The application interfaces and program utilization are presented.

INTRODUCTION

Despite regional variations, grid-based electric lighting consumes 19% of total global electricity production (IEA, 2006). In brazilian offices, for example, lighting represents 24% of the total consumption (LABEE, 2004). Partially, these large numbers are due to the fact that most electric lighting systems operate at full output regardless of outdoor light conditions. On most days, however, daylighting - represented by natural skylight or sunlight entering the building through windows - can provide sufficient light levels for the majority of human activities. Besides that, it has the major advantages of being a free source of light and promoting a higher perceived quality of the indoor environment. One other consequence of not integrating electric lighting and natural light includes unnecessarily high electricity use for lighting and air-conditioning (lighting can be an important source of heat in a building). In fact, because of all these reasons, to maximize efficiency, electric lighting shoud be treated as a suplement to, not a replacement for daylighting (Kwok, A., Grondzik, W., 2007). So, there is no real excuse to avoid artificial and natural light integration in the building design process.

One possible explanation why this integration is not part of the general behavior of the professionals involved with lighting is the lack of computer codes focused on the problem. There are a lot of computer codes developed to aid artificial lighting design - like DAYSIM, AGi32, LumenMicro (Rogers, 2007) - and some codes to assess natural lighting calculations. None of them, however, was intentionally developed having in mind these two lighting situations and its integration aiming the design process. As far as we know, the *Natlite* code which is presented in this article, comes to be the first product of this specific type. Its ability to quickly simulate both types of lighting systems greatly facilitates the lighting engineer in his task of optimizing his project.

NATURAL AND ARTIFICIAL LIGHT INTEGRATION

General considerations

Considering electric energy consumption, an ideal illumination system is the one designed to supply, as far as possible, the necessary light by using sunlight and skylight sources. This implies in developing a strategy based on artificially illuminating the interior environment only at the points where the natural light is insufficient, leaving to daylight the task of illuminating the other areas.

To implement such an integrated light scheme, the first step is to establish the horizontal illumination level that is a function of the planned tasks to be carried out inside the room. For offices, this level varies from 500 to 1500 lux, following brazilian standards (ABNT, 1992), or from 300 to 1000 lux - , according to IESNA (2000). After establishing the illumination level, the following stage is to proceed to the calculation of the artificial illumination necessary to supply that level, disrespecting the available natural light. This guarantees an artificial illumination system capable of performing efficiently at night time or during daytime when there is little availability of natural light.

It is well known that the illumination levels in one room lightened by a window present a distribution curve that has its biggest value at the surroundings of the vertical plane of the opening and the smallest value near the opposing wall of the room (in respect to the window wall). This fact leads to what seems to be a good strategy for efficient use of the natural light. It consists in dividing the interior environment in a certain number of stripes parallel to the window (source of natural light), and to associate each of these stripes to a corresponding electric circuit responsible to turn on and off the light fixtures inside it.

Considering the existence of automatic mechanisms to switch on/off these circuits the amount of natural light reaching each stripe (what it can be carried through with the aid of photosensitive sensors, for example), an hybrid illumination system is obtained, one that will only expend energy when and where it is really necessary. In other words, such strategy efficiently couples natural light devices (windows) to artificial light devices. In such a way, every use of natural light can automatically be considered a profit in terms of lesser consumption of electric energy with artificial light. Another important aspect of such a system is that it can be the lowest life-cycle-cost mean of lighting control (Kwok, A., Grondzik, W., 2007).

The energy savings achieved with such approach depend both on the amount of usable natural light available and the number of electric circuits adopted. Figure 1 below, shows the possible four situations that can occur with a four-stripe (four-circuit) configuration and their corresponding lighting profiles. Situation A happens when natural light levels are sufficiently high at all interior points, considering a pre-defined horizontal work plane. This is an ideal situation, when all electric circuits can be shut down and energy savings reach 100%, because only natural light is being used. Situation B represents periods of time when natural levels, although relatively high, are not sufficient to illuminate the most inner regions of the room. In this case, the farther circuit of artificial light must be turned on to help the window in its task of illuminating the room. As one of the four circuits must now be on, energy savings is therefore 75% of the maximum possible. Situation C and D are basically the same of situation B but representing cases where 2 and 3 circuits of artificial light must be turned on to illuminate ½ and ¾ of the room surface, because of a shortage of natural light. Obviously, there is one last possible light profile, not shown in figure 1, representing all light fixtures (four circuits) switched on, and no energy savings at all.

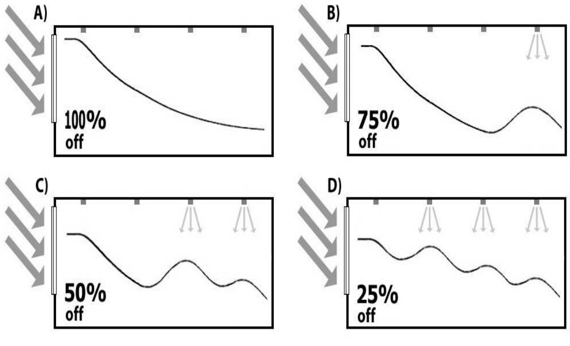

Figure 1: Possible energy savings when considering an artificial light system consisting of four circuits integrated with natural light use

Typically, during daytime these different situations can occur more or less randomly, mostly depending on sky clearness, geometric configuration of window and room, time of the year and geographic position and orientation of the building.

Concerning the electric circuits, a priori the deeper the room to be illuminated is, the bigger the number of stripes must be. This comes from the fact that the maximum depth natural light coming from a vertical window penetrates the room is more or less constant and equal to two times the height of the opening (Reinhart, 2005). This means that for "shallow" rooms the hybrid lighting system envisioned will, most of the time, work with all artificial lights switched on or off, since natural light, when available, will be capable to reach adequate illumination levels at all environment points. Therefore, in this case there is no real advantage in partitioning the electric circuits. On the other hand, for relatively deep rooms only the portion next to the window could be adequately naturally illuminated, deeper points having to be illuminated artificially. In this situation, the narrower each stripe of light fixtures, the greater the potential for savings and therefore the greater the advantage of considering natural light in the design.

The calculation approach

The methodology for the calculation of the amount of necessary artificial light throughout a certain period of time is based in the hourly distribution of light levels – due to natural light - on the study plane. For the assessment of these distribution, the room surface (or the study plane) is virtually divided in 100 small areas, in a matrix configuration of 10 by 10 elements (see figure 2). The simulation of the natural illumination levels is carried out for each hour of the day (6:00 am to 6:00 pm) at the centroids of each one of the 100 elements. To verify the need for artificial light, it is then considered the array elements that fall within the corresponding area for each one of the stripes (the lighting circuits, as described previously in the text). The criterion to establish if one lighting circuit can be turned off is: "*all* elements within one stripe must present calculated illumination levels - due to natural light only - superior to the recommended minimum level for the task". Figure 2B describes graphically this approach for a three-circuit configuration. To turn off the luminaries of circuit 1, the corresponding 30 elements must receive sufficient natural light. To turn off the next circuit (stripe 2), not only the first 30 elements, but also the next 40 must be well naturally illuminated. The same applies for the third circuit, in the deeper regions of the room. Obviously, the number of considered elements at each stripe will vary with the number of stripes defined for the artificial lighting system. For this last number, in the brazilian case, the scheme works better with the use of two, three or four stripes at most, to keep an adequate level of simplicity of the electrical circuits and the usual practices of the local construction industry.

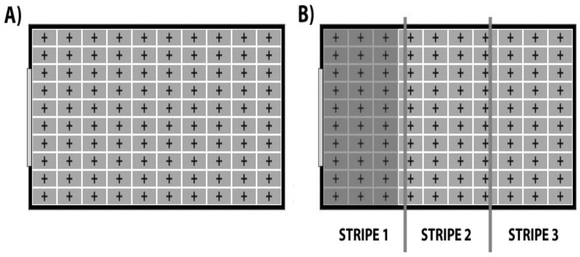

Figure 2: Room plan showing the virtual division of the room (A) and elements of each stripe in a three circuit configuration (B).

Integrated systems performance assessment

The systems (natural and electric lighting) integration performance is obtained considering the ratio between two calculated values:

1. the room working surface that is sufficiently illuminated by daylighting and
2. the total room working surface (here illuminated by artificial means).

Such ratio, calculated in an hourly basis and for a given light-fixture distribution, represents the achieved energy savings if electric light control systems are used to automatically compensate for the amount of available daylight, turning on and off some fixtures and maintaining a constant light level over time within the room.

METHODS AND MODELS FOR LIGHTING SIMULATION

In order to calculate natural light and artificial light inside a room, some methods and models were implemented in the computer code kernel.

Natural light assessment

Natural light calculation over one external surface is carried out through the Dogniaux's (1985) theorectical method. It is capable of predicting illumination levels (in lux) received by following some steps:

1. Knowledge of sky luminance distribution (in Cd/m²).
2. Knowledge of extraterrestrial solar radiation.
3. Establishment of some parameters (site geographic location, altitude, atmosphere turbidity) in order to model the absortance and scattering of radiation by the atmosphere.
4. Determination of the luminous efficacy (in lm/W) of the solar radiation, that is to say the part of the solar radiation crossing through the atmosphere that becomes effective in natural light, the values depend on the type of sky, atmospheric turbidity, altitude and the latitude of the site.

These steps allow the calculation of illumination levels over one external surface. In our case, this external surface is represented by the building facade where the window is installed. The validity of the Dogniaux's model was determined by comparing some simulated values to the experimental data obtained by Cavalcanti (1991) and Guimarães (2003) to the city of Rio de Janeiro. The results showed a good agreement between the two conditions (simulated and experimental).

To determine the amount of light striking an interior point, another series of calculation is necessary. The classical approach to solve this problem is based on the geometrical characteristics of the room (Hopkinson et al, 1966) and the radiative relations among its inner surfaces. The Flux Transfer Method, used within our computer code, is one of these methods (Robbins, 1986). Also known as the Finite Surfaces Method, it allows the calculation of interior illuminances and luminances, over surfaces and points, considering light reflections or of any order of the penetrating radiation. The method takes into account the luminous fraction of the solar radiation that strikes the surface of the opening (the exterior window) and the configuration factors of the existing surfaces inside the room. These configuration factors can be defined as the fraction of the diffuse energy radiated by a surface "A" that reaches another surface "B". These surfaces "A" and "B" can be infinitesimal surfaces or extensive ones and freely oriented, what means that configuration factors can be calculated for a infinity of distinct situations, making possible the simulation of reflections in rooms presenting a complex geometry.

Artificial light assessment

Artificial light systems are much simpler to calculate in comparison with natural light ones, due to the greater knowledge the design parameters. Like in the natural light assessment methods, artificial lighting is calculated considering the geometrical characteristics of the room. The difference is that the light source has a well known, well documented luminous distribution. Natural light, on the other way, suffers from the inherent instability of its natural sources, the sky and the sun. Light bulbs and fixtures luminous distribution curves are easily obtained from manufacturers and can be used to determine the exact illumination levels inside a room.

This can be done by what is called the Point-to-point method, which states that:

$$E = \frac{I\alpha}{h^2} \cdot \cos^3\alpha$$

where:

"E" is the illumination level (in lux);

"I" is the luminous intensity (in candles), taken from the manufacturer's bulb specification for the corresponding angle α;

"h" is the vertical distance from the light source to the study plane;

"α" is angle between the bulb-point direction and bulb-study plane direction;

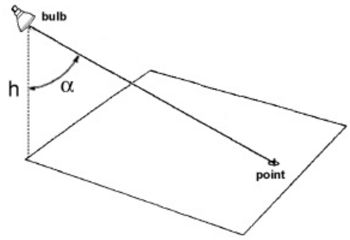

Figure 3: Point-to-point method parameters

THE COMPUTER CODE

In order to apply in a practical way the methods for calculating the lighting we described in the previous section, a computer code was developed. Called Natlite, it was compiled in a single executable file to be run under the 32-bit windows environment and presents the following calculation capabilities:

1. Total Solar Radiation and Incident Luminous Radiation on the external surface of the building facade.
2. Incident Luminous Radiation in any interior point of the room.
3. Daylight Glare Index in any interior point of the room.
4. Electric Energy Savings achieved with the use of natural light, in terms of percentage and KWh of the total artificial light necessary to get adequate levels of illumination, taking into account the number of electric circuits linked to the lighting fixtures (2, 3, 4 or 5 independent stripes).

Data entry is achieved with the help of five different windows. The first one – "SITE PARAMETERS" - allows entering data related to the geographic location, envelope characteristics of the building, and time of simulation (see figure 4). The simulation considers one pre-established day of the month, corresponding to the day where the solar declination presents an average value within the corresponding 30-day period. The building orientation sets the azimuth of the façade which contains the window to simulate related to geographic cardinal points (south=0°; north=180°; west=-90°; east=+90°). The environment albedo can also be set in this window, just like the meteorological station (in terms of the site's latitude, longitude and altitude) and the method used to simulate the sky conditions (Dogniaux or L'Ohm parameters).

The second window – "ROOM PARAMETERS" – is dedicated to the data related to the room dimensions (width, height, length) and to the reflectances of the interior surfaces (ceiling, floor and walls).

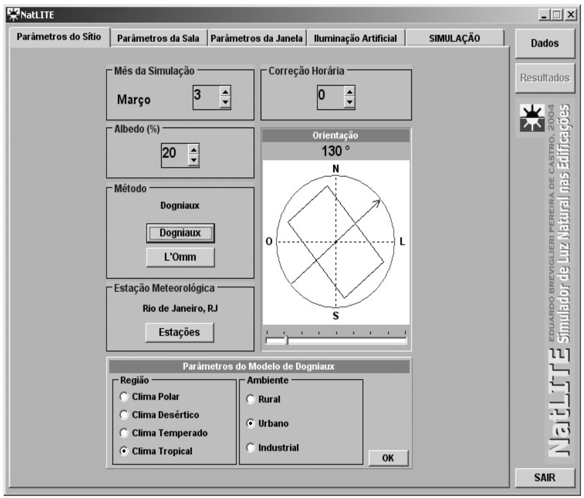

Figure 4: The SITE PARAMETERS window

Through the third window – "WINDOW PARAMETERS" – the user can enter the opening dimensions (height and width) and its position related to the floor (sill height) and to the left wall (see figure 5). Besides that, the main window characteristics can be set, as the glass type (transparent, texturized or plastic-made) and window frame thickness (thin, medium or thick).

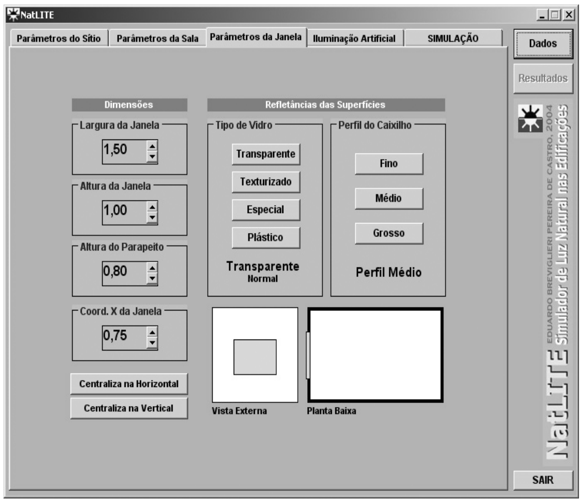

Figure 5: The WINDOW PARAMETERS window

The forth window (figure 6) is where the "ARTIFICIAL LIGHT PARAMETERS" are defined. Here the user sets the number of electric circuits ("stripes") parallel to the wall of the window, the daylight glare limit, the desired illumination level at the work plane and the type of lighting fixtures (luminaries' characteristics). The available fixtures are stored in a database file editable by the user, which is accessed by the "FIXTURE SELECTION WINDOW", where an image of it and its corresponding luminous distribution curves (in graphical and table forms) are shown to help the choice by the designer.

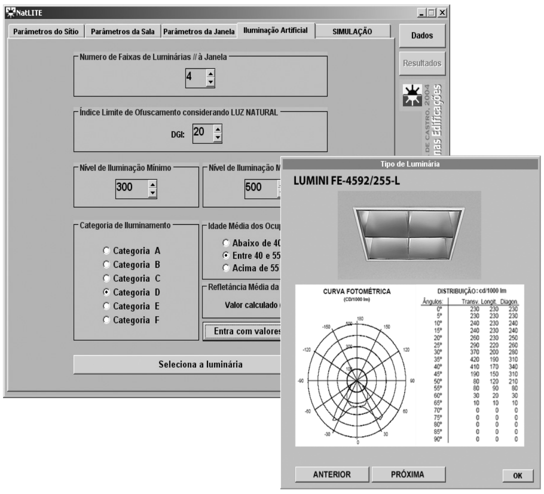

Figure 6: The ARTIFICIAL LIGHT PARAMETERS window showing the FIXTURE SELECTION window

The fifth and last window – "SIMULATION PARAMETERS" – presents entry-boxes to allow the user setting some simulation variables (luminous efficacy of solar radiation; and window shading factor) and a button to start up the simulation calculations.

Once initiated, the simulation process takes no more then a few seconds, even on a slow/old computer. When finished, the available tabs inside the code main interface automatically change to show all the calculated results. There are five distinct results windows.

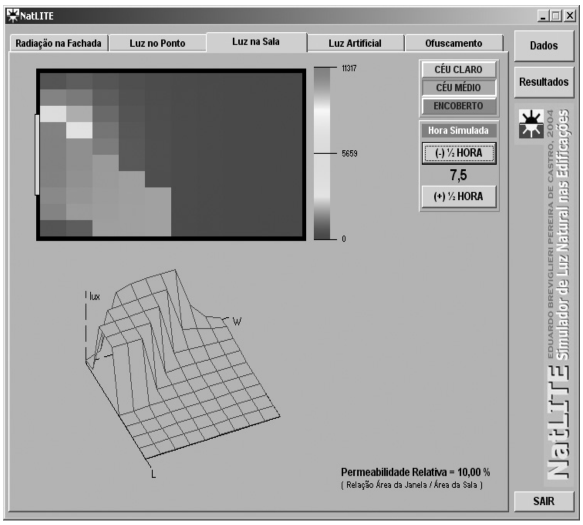

Figure 7: The NATURAL ILLUMINATION RESULTS window

The first one shows the radiation level and the illumination level on the facade's vertical surface, due to natural light (sunlight + skylight). The second window also shows the radiation levels and the illumination levels due to natural light, but on a specific horizontal point inside the room. The third windows (see figure 7) displays the natural light distribution on the work plane. As for the other results, three types of sky can be selected (overcast, perfectly clear and partially clear) for any daytime from 6:00 am to 6:00 pm with a ½ hour time step. A plan plot and a 3D mesh plot show the results.

The natural light and artificial light integration results can be assessed by selecting the forth results window (figure 8). It contains two plans of the room. The upper one displays the stripes partition, showing which circuits should be switched-on and which should be off, at the selected daytime and under one of the three sky conditions. The lower plan shows the luminaries distribution. To the designer concerned with energy savings however, more important is the graph displayed on the right lower corner of the window. Here the energy savings are available in an hourly basis. The global daytime savings is also shown.

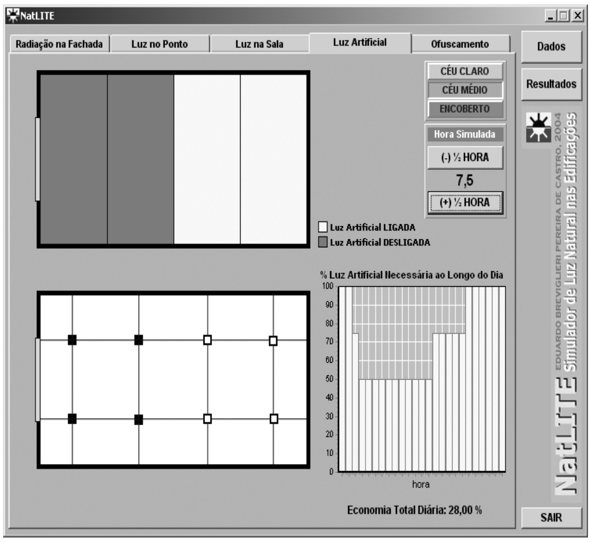

Figure 8: The ARTIFICIAL ILLUMINATION AND LIGHT INTEGRATION RESULTS window

EXAMPLE RESULTS

As an example of the savings that can be achieved with such integration, a simulation is presented. The case study is a generic room of 4 x 8 meters (width x length), illuminated by a window of 2 x 1 meters (width x height), centered in the facade wall of a building situated in Rio de Janeiro, Brazil. The simulations had been carried out considering clear sky conditions (February) and the facade oriented toward northeast (45 degrees in relation to the geographic north). The results are shown in table 1. One can perceive by the simulation results that savings above 20% are easily achieved. Due to the relative great depth of the room, the bigger the number of light stripes, the greater the savings, varying from 24.0% for a 2 stripes configuration up to 30.4% for a design with 5 stripes.

Table 1
Energy savings in the example case study

Number of Stripes	Savings
2	24.0 %
3	25.3 %
4	27.0 %
5	30.4 %

CONCLUSION

With *Natlite*, both calculations (natural and electric) can be carried out in a very fast way. The lighting expert envolved in the building design can then interactively experiment many configurations (window sizes and positions, fixtures distribution schemes) in order to choose a better solution for the lighting systems. In other words, this allows the optimization of the electric light system and helps architects, engineers and lighting designers the adoption of such calculations in their everyday practice in an easy and reliable way. We believe the developed computer application has the potential to aid engineers face the challenge of designing better and more sustainable buildings by making use of a natural renewable resource – natural light.

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