CADERNOS
PROARQ 18

EDUARDO BREVIGLIERI PEREIRA DE CASTRO

Theoretical evaluation of potential energy consumption reduction with artificial lighting by means of automated integrated systems

Eduardo Breviglieri Pereira de Castro is Civil Engineer (UFJF, 1986). Masters in Architecture (FAU/UFRJ, 1996). Doctorate Degree in Mechanical Engineering (COPPE/UFRJ, 2005) and in Civil Engineering (INSA de Lyon, 2005). Professor in School of Engineering at Federal University of Juiz de Fora. eduardo.castro@ufjf.edu.br

ABSTRACT

In Brazil, lighting represents about 22% of total energy consumption of commercial buildings. An envisioned solution for reducing this value is the integration of the building artificial lighting system to daylight, what can effectively occur when the artificial system - or parts of it - is switched on or off as a function of daylight levels reaching the indoor spaces. Such a strategy can contribute not only to energy savings but also to the global sustainability of the building. This paper presents the results of computer simulations carried out to determine the theoretical reduction in consumption with artificial lighting in an office building when using an integrated scheme of this type, in which electrical circuits are designed by placing luminaires in parallel bands to the window wall. The software used, Natlite, was developed for this purpose. Two types of sky conditions are considered in the simulations. Their proportions of width, depth and height determine the geometry of the rooms. Results show that by effectively integrating daylight from windows in buildings with the artificial lighting system, energy savings ranging from 25% to 95% can be achieved in the city of Rio de Janeiro. In the text, initially, the methodology used is described. Then, the data obtained is presented in tables and graphs. Finally, some considerations are made about the findings and implications of the results for an architecture project.

Keywords: Sustainable Building. Natural Lighting. Computer Simulation.

Introduction

The use of energy in buildings can be expressed by the quantity of energy consumed in their interior and direct surroundings. This consumption is due to distinct equipment uses, such as the interior's air conditioning and heating systems, electrical lighting (in the interior rooms and, in some cases, exterior surroundings and façades), electrical appliances etc. In Brazil, the highest shares in the commercial sector consumption refer to air conditioning and lighting, varying from 50% to more than 70% of this sectors' total consumption, depending on the segment. The demands, specifically with lighting, represent the second highest source of expenditures – 22% of the total (ELETROBRÁS, 2011).

We must take into account the current national and international situation and the energetic system complexity – embarrassment in the energy generation structure increase to attend the crescent levels of this resource's demands and, at the same time, aiming at a reduced environmental impact. It is strategic to think of solutions that will contribute to address this issue. A possible path is the exploration of rational renewable resources to substitute electromechanical equipment with similar operational functions. While focusing on this approach seems difficult to solve some problems – the heating of buildings, for example – nature may provide, in other cases, alternative resources that may be easily put to good use. Natural light in buildings, at least during the diurnal fraction of the 24 hours period when there is light provided by sun and sky, may substitute the traditional system based in electric lamps.

At least two premises validate the importance of this approach. First, there is a strictly economic factor, since with current available technology saving energy is more cost effective than producing it. Just to give an idea, according to data by ELETROBRÁS (2011), "the theoretical savings in residential, commercial, services and public buildings could achieve 53 billions KWh. The energy saved would be sufficient to annually supply about 2,7 million residences". Still according to this source, "in new buildings, using energy-efficient technologies from the first design conception, the consumption economy could achieve more than 50%, if compared to a building conceived without the use of these same technologies".

Moreover, the obtained economy reverts in benefits to the environment, since the environmental impacts are reduced. It occurs like a collateral effect, not as other investments costs, but as an additional profit; which implies that the energy saved, better saying, made good use of, becomes a new "source", cheaper, cleaner and sustainable. This leads us to the second premise: the co-relation of production, use and environmental sustainability. In reality, among the seven principles of the "sustainable building" (KIBERT, 2008), at least three apply to the rational natural light use: (i) reduce resource consumption; (ii) apply a cost analysis based on the building's life cycle; and (iii) focus on quality. In general, out of these three principles, only the first is normally considered in a project that is intended to have a natural light sustainable use. The cost of a system that integrates natural and artificial light is also profitable if we think that additional installation costs can be more than compensated by the reduction in the energy consumption during the building's life cycle. Besides, in terms of quality, no other artificial light source offers the same visual comfort to the user, if compared to natural light.

Ideal Lighting Strategy

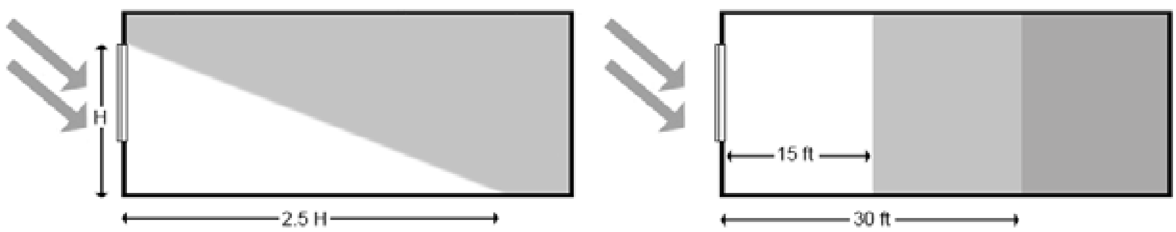
According to the above considerations, the ideal lighting calculation, in terms of electric energy consumption, is directly related to the percentage of light necessary to illuminate a room, which can be supplied by sun and skylight. This implies in the development of an interior artificial lighting strategy, only based in the interior parts and moments when natural light becomes insufficient. Architects and engineers who are involved with lighting are already using, somewhat frequently, simple approaches to apply this strategy in their projects. Two well-known strategies are the rule 2.5H and the rule 15/30 (KWOK and GRONDZIK, 2007). The first establishes that natural light may be capable of penetrating a room into a depth 2.5 times the height of the opening (window). The second rule indicates that a well-designed opening, in general: (i) is able to naturally illuminate a room up to a depth of 15'; (ii) is able to naturally illuminate a room with the aid of artificial lighting from 15 to 30' into the room; and (iii) is not able to illuminate depths beyond 30' in acceptable levels, which requires the mandatory use of artificial devices beyond this distance (Figure 1).

Despite being practical, these rules are excessively simple, hindering the atteinment of satisfactory results in terms of optimum energetic consumption.

FIGURE 1

Simplified rules to guide windows dimensioning in relation to natural light. Rule 2.5H to the left; and rule 15/20, to the right.

(Source: adapted from KWOK and GRONDZIK, 2007)



In the available literature, there are many other sophisticated approaches and studies on efficiency strategies for integrating artificial and natural light use. Ihm et al. (2009), Krarti et al. (2005) and Li et al. (2003) worked on this concept grounded, however, in propositions of lamps dimerization or artificial light circuit-breaking in the perimeter of rooms (close to the windows).

A different and simpler approach, although not less precise, can be suggested and developed, based not on dimerization of lamps or in the use of sophisticated lighting devices, but on simple subdivision of electric circuits in the lighting design project. An advantage of such a scheme is its easy understanding and application, both for new buildings and for retrofit projects.

The dimensioning initially demands the knowledge of lighting indexes that are related to the tasks done in the interior. In the case of offices, for example, this index varies, according to distinct norms, from 200 to 1000 lux. Once the minimum level of appropriate light is established, the next phase is the dimensioning of artificial light needed to supply the interior, not taking into account the available natural light. This guarantees an appropriate light for night hours or periods of little natural light availability.

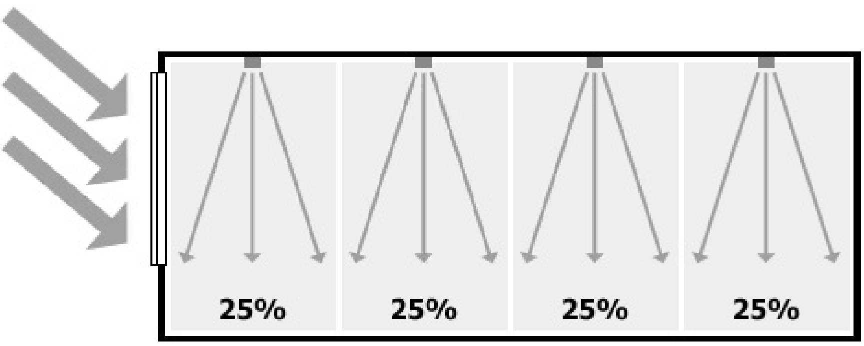


FIGURE 2

Transversal cross-section of a room showing an example of an artificial lighting scheme with 4 bands of luminaires parallel to the wall window.

(Source: the author)

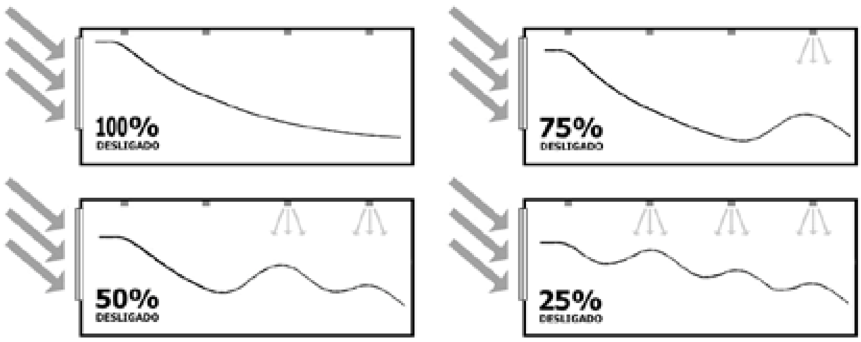
Next, based on the fact that light levels in a room lit by a window form a distribution curve that presents its major value close to the opening plan, and its minor value close to the wall opposite to the window – as rule 15/30 indicates –, one may realize that a good strategy for effective natural light use consists in theoretically subdividing the horizontal area of the room in a certain number of bands parallel to the wall (Figure 2). Then, each of these bands is associated to an electrical circuit corresponding to the luminaires aligned in the band. Finally, concluding the strategy, the existence of automatic mechanisms to switch on/off these circuits may be considered according to the amount of natural light reaching each band – which can be done with the aid of photoelectrical sensors, for example).

An integrated lighting scheme is obtained, thus, in which the light energy consumption will only occur where and when it is really necessary. That is, natural light devices (windows) will be coupled with artificial light devices. In this sense, all use of natural light system may be automatically considered as a gain, since there is less artificial light energy consumption.

The energy savings obtained with the above-described scheme will depend both on the amount of natural light available, and on the number of electric circuits defined. In a four bands' scheme, for example, depending on the amount of available natural light, we may obtain an immediate reduction of 25, 50, 75 or even 100% of the total consumption (Figure 3).

FIGURA 3

Transversal cross-sections of a room showing different forms of artificial light use and respective lighting curves in a scheme of four luminaires bands parallel to the wall plan.



As a generic rule, the number of bands must be the higher the deeper is the room to be lit. For interiors not so deep, the lighting scheme proposed will work with almost all luminaires switched on or off along a daylight period, since natural light, when available, will provide satisfactory light levels in the whole interior. In this case, there would be no gain in subdividing the electric lighting circuits. On the other hand, for relatively deep rooms, only the parts closer to the window will be adequately lit by sun or daylight, while the back of the interior must be lit artificially. In this situation, the narrower the luminaires band, the better the use of natural light and, consequently, more potential savings. In practice, however, these schemes will work better with the use of 2, 3 or the maximum of 4 bands, keeping an adequate level of simplicity in the electric circuits in order to meet the usual construction industry standard. In that sense, for this research considered and determined the efficiency of a scheme of three luminaires in each band.

The efficiency of this strategy will depend upon the window position in relation to the wall, besides the room depth. A narrow room has the potential to be totally lit by natural light, but this will only occur if the window has a sufficient size and is well located in relation to the interior areas to be lit. If the window is located too far from the room's central axis, a good part may not present the minimal lighting levels sought, forcing the use of artificial light during almost all the time to light the darker side of the room. As a direct consequence of this limitation, we conclude that the integrated lighting scheme works better in commercial buildings, where opening are generally located along the whole width of the room, no presenting "shadow spots".

With all these particularities, the following question emerges: facing so many distinct variables, what is the true consumption reduction potential with the use of this system? The following methodology was developed to answer this question.

Methodology

Based on the above-described scheme, a methodology for the dimensioning of the amount of artificial light necessary along a certain period is grounded on the timely distribution of illuminances over a given horizontal plan surface. In order to determine this distribution, the surface of a room can be theoretically subdivided in a grid of small areas, as a matrix configuration (Figure 4).

Then, the illuminances for each hour of the day in the geometric center of each of these areas are calculated. This procedure provides the lighting levels distributions. In order to verify the artificial lighting real need, the matrix elements contained in the areas of each artificial light band (circuits) are considered in a given moment. The criteria used, in order so the circuit lamps are switched off, is that all elements in the considered band must present illumination levels higher to the minimum defined for the task (Figure 4). Obviously, the number of elements considered would vary by the number of bands in which the artificial light scheme was divided.

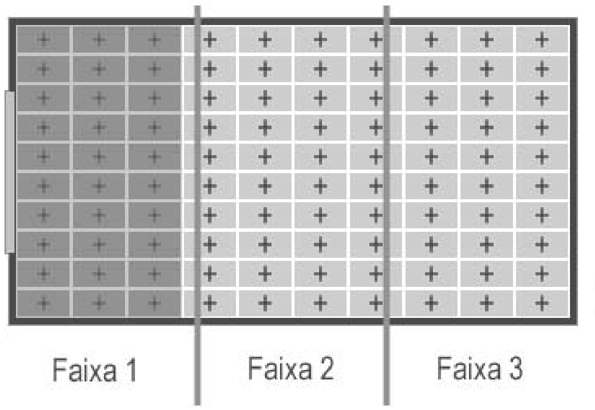


FIGURE 4
Plan view of a room showing a grid with spots used by software NatLite in the calculation of artificial light use profiles, for a three bands of luminaires scheme parallel to the window.

(Source: the author)

All the above-described dimensioning can be done simply, using a computational code developed for this task. For the present study, we used software Natlite (CASTRO et al., 2011; CASTRO, 2005). It determines the interior illumination levels based on Dogniaux's (1985) model. In order to determine the electric energy savings potential for a broad range of room geometries, 56 simulations were done, considering some basic parameters: number of electric circuits, simulation location, façade orientation, window dimensions, minimum level of illumination for the realization of tasks equal to 300 lux, two types of distinct skies and 28 room dimensions proportions.

The chosen illumination level was the least possible for office areas, according to NBR-5413 - item 5.4.13 (ABNT, 1992). The energy consumption reduction was obtained by comparing the total energy used during 12 hours (6am to 6pm) with artificial lighting, and the total energy consumed during the same period with artificial lighting; the former considering the use of an integrated system; the latter, a traditional system without the use of natural light (uniquely artificial lighting).

The choice of the façade orientation was south, because it is the one with the least natural light use problems in our hemisphere. For the chosen region, Rio de Janeiro, this orientation allows the window exposition to the sky dome without much concern regarding the thermal charge provided by direct solar radiation exposition of some periods of the year. For other orientations, the study would have to be more comprehensive, since the presence of direct solar radiation would require the prediction and use of solar protection systems during most of the year, changing significantly the performance of the integrated lighting system.

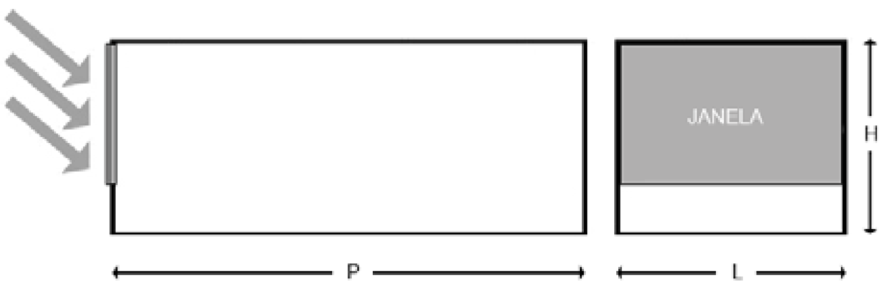
Regarding the typology and dimensions of the window, all the simulations considered an opening that reached the whole width of the room, as well as the distance from the windowsill (h=0.75m) to the ceiling. By doing that, for each relation P/L and H/L, the window dimension varied proportionally (Figure 5).

The two types of skies were considered: (i) totally overcast sky; and (ii) clear sky, no clouds.

FIGURE 5

Aspect of the window and geometry of the rooms used in the simulations: left – cross-section; right – elevation.

(Source: the author)



In terms of the room geometric proportions, seven different relations of the room depth and width (P/L) were considered and four different relations of the room height and width (H/L). The proportions P/L considered were: 1, 4/3, 5/3, 2, 7/3, 83 and 3. That is, the simulated rooms had a relation of width and depth varying from 1 (depth = width, room with a square surface) and 3 (depth three times higher than width). In turn, the proportions H/L considered were: 1, 4/3, 5/3 and 2, that is, varying from 1 (height = depth) to 2 (ceiling height twice the value of the room width).

A natural light illumination level of 300 lux was also considered as the minimum value to trigger the electric circuits interruption in the simulations. As a last parameter, all calculations were done based on a three electric circuits (luminaires) parallel to the wall where the window was located.

Results

With the use of the above-described methodology, values that varied from 0 to 1 were obtained for the 56 simulations. A 0 (zero) value indicates that no gain was achieved with the use of the proposed system, and value 1 (one) represents 100% reduction in the electric lighting consumption (with use of natural light only). The results are organized in Tables 1 and 2. The first table considers a clear sky condition and the second table, an overcast sky condition.

Important to note is that although data represents values for the simulations considering March 21st as the experiment's date, other simulations, which results are not shown in this work, were done for all months of the year and they did not present significant variations in the corresponding values. Several other simulations were done as well using different room dimensions, maintaining, however, proportions P/L and H/L.

Also in these cases, values found did not present significant variations in relation to the data in the tables. This indicates that the most important thing for the proposed lighting system efficiency is the geometric proportions of rooms and not the absolute dimensions of them.

In order to make the results analysis easier, they were treated and then organized graphically, co-relating the consumption reduction with the room geometric proportion P/L for each sky condition. Thus, four curves representing

TABLE 1

Energy consumption Reduction with Artificial Lighting / Orientation South / Clear Sky / Imin=300

(Source: the author)

P/L H/L	1	4/3	5/3	2	7/3	8/3	3
1	0,93	0,93	0,92	0,88	0,84	0,81	0,56
4/3	0,95	0,93	0,93	0,92	0,91	0,87	0,83
5/3	0,96	0,93	0,93	0,93	0,92	0,91	0,87
2	0,96	0,95	0,93	0,93	0,93	0,92	0,91

TABLE 2

Energy consumption Reduction with Artificial Lighting / Orientation South / Overcast Sky / Imin=300

(Source: the author)

P/L H/L	1	4/3	5/3	2	7/3	8/3	3
1	0,84	0,73	0,57	0,43	0,28	0,25	0,25
4/3	0,87	0,8	0,75	0,61	0,45	0,40	0,28
5/3	0,88	0,84	0,79	0,72	0,63	0,45	0,43
2	0,88	0,85	0,84	0,77	0,71	0,63	0,47

the distinct H/L relations are traced in each graph (Figures 6 and 7). The curves were built through polynomial adjustments of degree 3 of data obtained in the simulations.

The observation of the results allows some considerations.

First, we immediately perceive that the energetic consumption variation reduction is much higher for the overcast sky conditions than for clear sky, and that this amplitude is related both to the room proportion H/L and to room proportion P/L. This indicates that for regions with overcast sky increases in the room height, and consequently in window dimensions, proportionally brings more benefits in terms of energetic consumption with lighting, than that for regions with clearer sky. Moreover, the integrated system efficiency variation in this situation is also related to the room depth. Spaces with depths three times their width are approximately three times less efficient with the use of natural light, than square-surfaced spaces, under an overcast sky condition. This suggests that in places where overcast sky is prevalent, the priority should be given to less deep space designs.

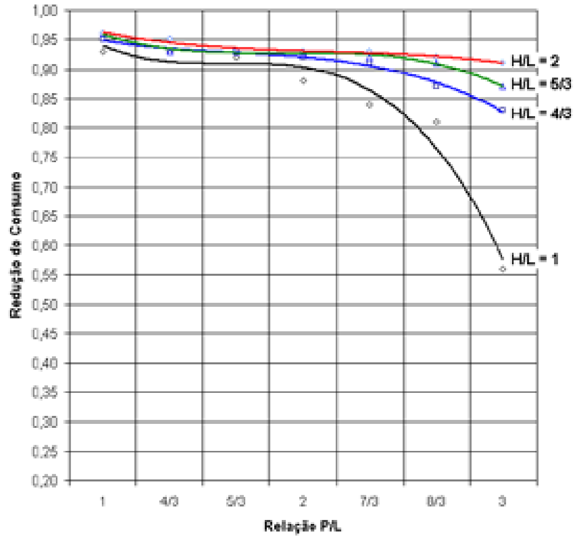


FIGURE 6
Consumption reduction with artificial light in room relations of Depth X Width and Height x Width; CLEAR Sky condition; Orientation South; Lmin=300 lux; considering 3 light circuits.

(Source: the author)

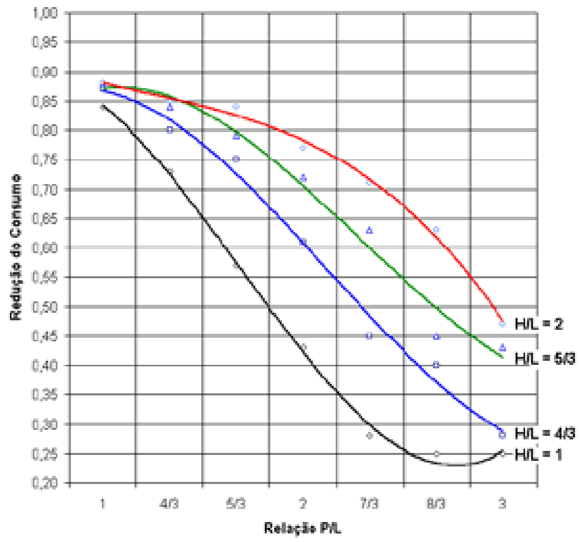


FIGURE 9
Consumption reduction with artificial lighting in room relations of Depth X Width and Height x Width; OVERCAST Sky condition; Orientation South; Lmin=300 lux; considering 3 light circuits.

(Source: the author)

Concluding Remarks

These results, generated by the data treatment in the simulations, may serve as support to Engineers' and Architects' decisions, in matters regarding spaces dimensioning and integration of a renewable resource, natural light, to buildings. It is demonstrated that a good strategy to achieve a significant reduction in the energy consumption in built environment is the use of automatized integrated systems, considering the subdivision of electric light circuits in bands.

Through the simulations, we conclude that this reduction may vary from 25% to 95% of the total energy consumption used for lighting in the city of Rio de Janeiro, depending on the geometry of the room and on the illumination provided by the sky. We may also affirm that values of the same magnitude are obtained for any geographic location with latitudes close to the simulation case. These results are in accordance to other interior lighting efficiency studies existent in scientific literature, which are based, however, in other approaches, more complex, but less adapted to the Brazilian reality. Differently from other propositions, the scheme presented is characterized by simplicity and low implantation cost. It can be applied indistinctly in existing buildings – in retrofit cases – or in new buildings. We must emphasize that, even without the automatization of light circuits controls, or yet, even if the control is left in charge of the building's users, to be done manually, a consumption reduction may be achieved, depending on their awareness and concern regarding energy consumption, as an attitude that represents a significant contribution for the search for more sustainable buildings.

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