ANALYSIS OF DAY LIGHTING IN THE ENERGY SAVINGS OF ARTIFICIAL LIGHTING AND AIR CONDITIONING SYSTEMS OF COMMERCIAL BUILDINGS

José Henrique Martins Neto
Centro Fed. de Educ. Tecnológica de Minas Gerais, Dept. de Eng. Mecânica, Av. Amazonas 7675, Belo Horizonte, MG, Brazil
henrique@des.cefetmg.br

Ana Angélica Machado Máximo
Centro Fed. de Educ. Tecnológica de Minas Gerais, Dept. de Eng. Mecânica, Av. Amazonas 7675, Belo Horizonte, MG, Brazil
aammaximo@uol.com.br

Viviane Cristina da Costa Jorge
Centro Fed. de Educ. Tecnológica de Minas Gerais, Dept. de Eng. Mecânica, Av. Amazonas 7675, Belo Horizonte, MG, Brazil
vivianedcj@des.cefetmg.br

Abstract. *This paper presents the factors that contribute to the electricity savings in commercial buildings when day lighting controllers, type "dimming", are used to take advantage of day lighting. A correlation, developed previously from a simplified model, is presented and used to predict the energy consumption due to artificial lighting. The coefficients of this correlation were obtained for three Brazilian cities representatives of different weather, geographic location, and three minimum control fractions for the dimmers. This correlation is able to predict the electricity consumption for different floors layouts, windows areas and type of glazing. It was observed that glazing with high transmittances, cities with high solar radiation level and dimming controllers with lower control fraction contribute to the increase of electricity savings associated to artificial lighting. For the three cities analyzed it was noticed that the electricity consumed by the air conditioning system increased with the increase of the window area. For the city with the lowest solar radiation level, it was observed that the electricity savings due to the air conditioning system decreased with the increase of the window area. Additionally, for all three cities it was observed that the total electricity energy consumption increased with the increase of the window area, increase of the glazing transmittance and increase of the of the minimum fraction of the dimming controller. It was not observed a significant difference of electricity savings when the dimming minimum control fraction becomes lower than 0.1. A simplified economical analysis shows the savings that can be obtained when using day lighting.*

Keywords: *air conditioning, day lighting, simulation*

1. Introduction

Commercial Brazilian buildings represent approximately 13% of the total energy consumption in Brazil, being the electricity consumed by artificial illumination estimated in 44% and the air conditioning 20% of the average consumption. This statistic includes both the commercial and public buildings as related by SEBRAE (2002).

The electricity consumed by illumination with artificial lighting can reach up to 80% of the total building consumption. On the other hand, the energy consumption due to air conditioning systems can reach up to 50% of the total monthly energy consumption of these buildings conforms SEBRAE (2002).

In the last decades some measurements have been considered in order to reduce the use of electricity associated to the use of artificial illumination. Measurements of energetic efficiency commonly used according SEBRAE (2002) are: (i) use of compact fluorescent fixtures; (ii) use of electronic reactors with high power factor; (iii) installations of occupancy sensors; (iv) turn off fixtures (i.e., delamping); use of independent switches; and better projects to minimize the number of fixtures. Despite the air conditioning is recommended to maintain the indoor temperature close to 24 °C, conforms ABNT (1980) and ASHRAE (1997); turn off the air conditioning in unoccupied zones; conduct regular maintenance such as clean periodically air filters.

These measurements can carry out substantial energy savings and costs reduction either for new or retrofitted buildings, however, even though beneficial these measurements do not eliminate the continuous use of the artificial lighting for illumination of the buildings neither decrease deeply the energy consumption due to air conditioning.

Recently, architects and engineers have shown interest by designs that integrate the use of day lighting to reduce the energy use of the building. Most of the commercial buildings operate during daytime and, therefore, they can take advantage of the abundant availability of day lighting.

Recent researches show that there is crescent concern in take advantage of the day lighting in the commercial Brazilian buildings, conforms CEMIG (2002), however, so far there is no information of specific projects that have been developed using control strategies to use day lighting. Although, the technology of dimming controllers to be used with fluorescent illumination system reports from around 20 years, in Brazil this technology is recent and has not been frequently used mainly due to the high costs of special ballasts and dimming controllers.

Different past works show that is very common the excessive illumination in Brazil. The resistance of professionals, who work in the construction sector, regarding the integration of day lighting in their projects is in part due to the lack of simplified tools for design and analysis evaluation of the impact day lighting related to the energy savings.

Nowadays there are soft wares of high power of resolution available for building simulations. These soft wares have the capability to analyze the impact of the use of day lighting in the energy building consumption, however, the learning curve of these soft wares are time consuming for the end users (i.e., architect and engineers), which has contributed to the use restricted of these soft wares. A few simplified models also have been developed such as the simplified correlation proposed by Souza and Pereira (1995) and the PALN method described by Lino et al (1999) for prediction of energy savings due to the use of day lighting. However, these methods are limited to a specific floor layout and a specific site. A recent simplified correlation using dimensionless parameters of the building has been reported by Erickson et al (2005), however, its validation has been performed only for American cities.

The first goal of this work was to determine the appropriate coefficients for the Erickson (2005) correlation, for three Brazilian cities, representatives of different weathers and locations (i.e., northeast, southeast and south). This task was accomplished through various simulations using the building simulation program “DOE-2”. The electricity savings due to artificial illumination was analyzed for different parameters of the building and cities. The second goal was to evaluate the impact of the use of day lighting in the energy consumption of the air conditioning system, considering different building parameters and cities. This task was also performed though various simulations using the soft ware “DOE-2”. The simulations performed in this work also took in account three different minimum dimming fractions (i.e., the ratio between the minimum electrical energy power that the dimming control is able to deliver to the controlled fixtures and the maximum electrical power of the controlled fixtures, equal to nominal electrical power of the fixtures).

2. Model Description

The analysis is based on a commercial office building typically found in the Brazilian cities. The building has 10 stores, each one having 3 m of high, a plenum above the ceiling with 1 m of high, and 3600m^2 of floor area. The first focus of this work was to evaluate the electricity savings related to artificial illumination when using dimming control to take advantage of day lighting.

The following building parameters were used in this analysis: “Af” is the total floor area of the building; “Ap” is the total periphery floor area of the building, considering 4m deep; “Aw” is the total glazing area of the building (i.e. the total window area);

Typical values of the input variables, recommended to office commercial buildings, were used in the simulations as follows: illumination density of 14 W/m^2 according ASHRAE (1997); occupancy schedule from 8 am to 12 am and 2 pm to 6 pm; level of luminance in the desks of 500 lux; and internal shading caused by closing of roller shades or curtains when solar radiation exceeds 95 W/m^2.

It was considered five zones per floor, being four along of the building perimeter (i.e., North, East, South and West zones) and an interior zone in the core of the floor. The perimeter zones are composed by multiples office rooms of 3 m of width and 4 m of deep.

3. Parametric Analysis for artificial illumination savings

It was performed different parametric analyzes using the simulation building program “Doe-2”. The first group of analyses will be focused on the electricity savings related to artificial illumination considering: (i) different types of glazing; (ii) different window area apertures, defined as “Aw/Ap” (i.e., the ration between window and perimeter floor areas – this ratio allows the visualization of the window area related to the entrance area for day lighting).

The following three cities were selected for simulation because they represent different climate, solar radiation, and geographic location: (i) Fortaleza (latitude of -25.4° and 21 m of altitude, northeast region); (ii) Belo Horizonte (latitude of -19.9° and altitude of 800 m, southeast region); and (iii) Curitiba (latitude of 25.4° and altitude of 935 m, south region).

3.1. Analysis of the glazing

In this analysis four different types of glazing have been simulated in order to verify the effect of the glazing transmittances in both solar and visible wavelengths. These glazing were selected to cover a large range of transmittance and provide a good representation of the glazing types available in the market. Table 1 shows the different glazing with their transmittances values in the visible wavelength, the solar heating gain coefficient “SHGC” (i.e. the fraction of incident irradiance that enters the glazing and becomes heat gain, including both the directly transmitted solar radiation and the absorbed and re-emitted radiation), and the ranges of the simulated “Aw/Ap”. The following additional parameters have been used in the simulations: (i) “Ap/Af ” that is the ratio of the perimeter and floor areas (i.e. this ratio allows to visualize the part of the floor area that can be illuminated by the sun); (ii) Percentage of energy savings (i.e., percentage of the energy savings due to the use of day lighting compared to the base case - no day lighting control).

Table 1. Description of the glazing parameters and the range of the ratio “Aw/Ap” used in the simulations.

Type of glass	Number of panes	Visible transmittance	Solar Heat Gain Coefficient (SHGC)	“Aw/Ap” Range
“SC” Single clear	1	0.898	0.86	0.1 -0.7
“Sgy” Single Grey	1	0.611	0.712	0.1 -0.7
“Dclear” Double Refl D clear IG6/6/6 mm	2	0.307	0.421	0.1 -0.7
“Dtint” Double Refl C tint -M IG 6/6/6 mm	2	0.1	0.208	0.1 -0.7

Figure 1 shows the percentage of electricity savings issued in the artificial lighting system due to use of day lighting (compared to the base case -no day lighting), for different types of glazing (i.e., different values of visible transmittances and “SGHF”) for different “Aw/Ap” ratios, for the city of Belo Horizonte.

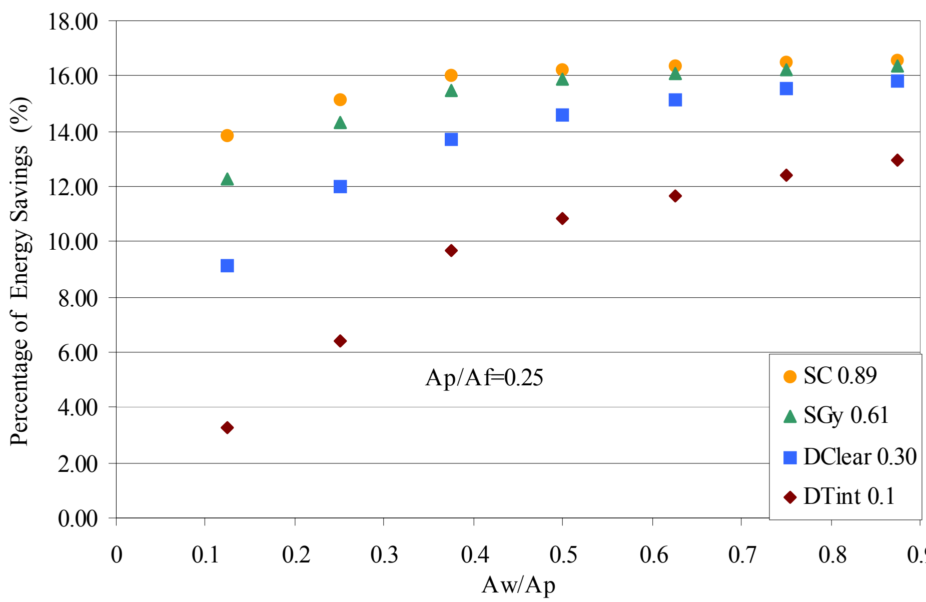

Figure 1. Analysis of the percentage of electricity savings considering different types of glazing and ratios “Aw/Ap” for the city of Belo Horizonte.

Figure 1 shows that for all glazing the increase of “Aw/Ap” carries out an increase of the percentage of the energy savings due to artificial lighting. The increase of “Aw/Ap” means an increase of the window area, considering the same perimeter area, and therefore, higher aperture area for the entrance of day lighting. Figure 1 also shows that the increase of the glazing transmittance promote increase of the energy savings, however, for transmittance values higher than 0.4 there is no significant increase of the energy savings, except for the “Dtint” glazing, which has the lowest values of visible transmittance and “SHGF”. The most significant savings is provided by the single clear glazing, which has the highest values of visible transmittance and “SHGF”. It was verified the same behavior of the other two cities analyzed in this work.

3.2. Analysis of the climate

Another important factor analyzed in this work was the influence of the site location in the electricity savings issued in the artificial lighting system due to the use of day lighting. The site location has its particular climate and, meteorological variables such as annual solar radiation and precipitation index can affect the availability of day lighting.

Figure 3 shows the percentage of electricity savings in the artificial lighting system related to the "Ap/Af" ratio as a function of day lighting aperture (i.e., the product of the transmittance versus the ratio "Aw/Ap"), for the cities of Fortaleza (region Northeast), Belo Horizonte (region southeast) and Curitiba (region south). "Ap/Af" works like a multiplicative factor of the collected energy savings, because as the perimeter floor area increases the energy savings increases linearly. Therefore, this is a convenient way to express the energy savings and can be applied for every floor layout.

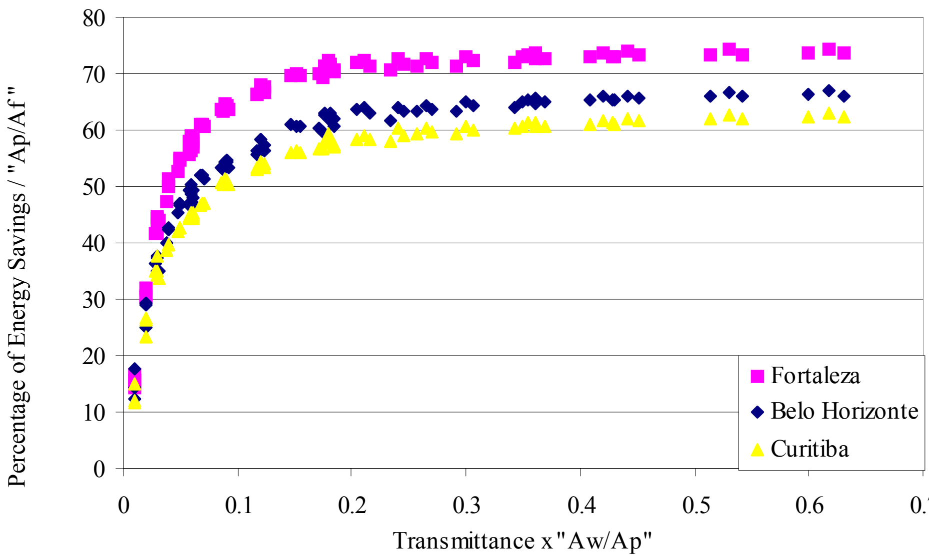

Figure 2. Analysis of the percentage of electricity savings considering the cities of Fortaleza, Belo Horizonte, and Curitiba.

Figure 2 shows that the climate affects the availability of day lighting. It was verified that the city of Fortaleza (close to the equator line) presents the highest percentage of energy savings. In fact, Fortaleza has the highest annual solar radiation energy (kWh), the highest number of sunshine hours per year, while its annual precipitation index is lightly higher than the other two cities. It was also verified that the city of Curitiba shows the lowest value of annual solar radiation energy (kWh) and the lowest number of sunshine hours per year, even though it has the lowest precipitation index.

Equation (1) presents the correlation based on the model presented by Erickson et al. (2005):

$$\frac{f_d}{A_p/A_f} = b \times [1 - \exp(-a \times \tau_w \times A_w/A_p)] \quad (1)$$

Where: "fd" is the percentage of energy savings; "τw" is the visible transmittance; and "a" e "b" are the constants depending of the location of the city.

A statistic analyses have been performed to obtain the coefficients for the correlation above, for the three Brazilians cities studied in this work.

Table 2 shows the coefficients "a" and "b" of the Eq. (1), for the cities of Fortaleza, Belo Horizonte and Curitiba, obtained from an statistical analyses of the data showed in Fig. 1.

Table 2. Coefficients of the Eq. (1) for the three Brazilian cities

Cities	Coefficients		Latitude
	a	b	
Fortaleza	29.0	71.5	3.3º
Belo Horizonte	26.3	63.4	19.9º
Curitiba	24.6	59.2	25.4º

The coefficients "a" and "b" have a physical meaning. The coefficient "b" represents the maximum percentage of energy savings possible to obtain when taking advantage of the day lighting. This occurs when the day lighting aperture (i.e., the product of the transmittance versus the ratio "Aw/Ap") tends to infinite. The coefficient "b" can be seen as an indicator of the availability of day lighting during the building operating hours for a specific site and represents the percentage of hours along the year that day lighting is enough to attend alone the illumination level (500 lux) required for visual comfort (i.e., without turn the lights on). The coefficient "a" represents the potential of the site to take advantage of the availability of day lighting. In other words, high values of "a" mean that smaller values of the day lighting aperture are required to take advantage of day lighting. In the ideal situation the coefficient "a" tends to "∞", which means that for any day lighting aperture the energy savings will be always maximum and equal to the coefficient "b". The coefficients "a" and "b" depend on the climatic conditions as well as the site location.

3.3. Analysis of the control strategy

The most typical controllers used in commercial buildings to control artificial illumination, as a function of the availability of day lighting, are the continuous dimming and multiple step dimming. Figure 3 shows a five and three step dimming controllers, as well as a continuous dimming controller. "Fl" is defined as the output light fraction (i.e., the percentage of artificial illumination related to the maximum illumination of the fixture); "Fp" is defined as the input electricity power (i.e., the power consumed in the fixture related to the maximum electricity power consumed by the fixture to provide the maximum illumination); "Fl,min" and "Fp,min" are, respectively, the minimum output fraction and the minimum electricity power, which depend on the characteristic of the dimmer. The continuous dimming controller presented in Fig. (3) considers the "Fl,min" and the "Fp,min" equal to zero (i.e., the ideal controller).

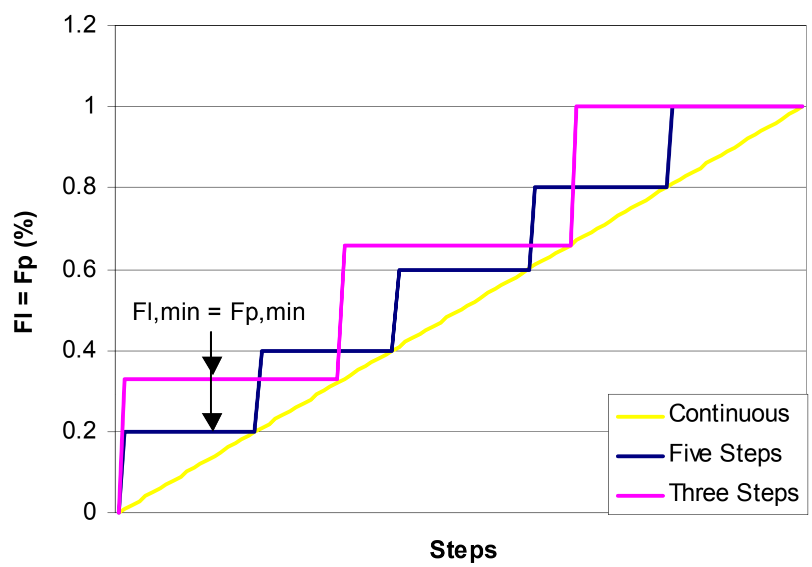

Figure 3. Typical dimming controllers used in commercial building.

From Fig. 3 can be figured out that the best type of controller is the continuous dimming controller. This type of controller delivers the exact amount of lighting required to attend the luminance level of the space. Therefore, this controller shows the lowest energy consumption and, consequently, provides the highest energy savings.

In this work, it has been simulated only the continuous dimming controller considering three different minimum fractions. Table 3 presents the correlation coefficients "a" and "b" obtained through statistical analysis, considering data obtained from simulations for the three cities mentioned previously.

Table 3. Analysis of the minimum fractions "Fl,min" and "Fp,min" for the cities analyzed in this work.

Cities	Minimum fractions for the continuous dimming control					
	$F_{L,min}=F_{P,min}=0.01$		$F_{L,min}=F_{P,min}=0.1$		$F_{L,min}=F_{P,min}=0.3$	
	a	b	a	b	a	b
Fortaleza	26.7	78.4	29.0	71.5	35.9	64.4
Belo Horizonte	24.4	69.5	26.3	63.4	32.5	49.7
Curitiba	23.0	64.8	24.6	59.2	30.0	46.6

As expected, the minimum fraction has a significant effect on the performance of the artificial lighting systems when using day lighting. For all the three cities analyzed in this work, the coefficients "a" decreases and "b" increases as the minimum factor decreases. High values of "b" coefficient means more availability of day lighting. On the other hand, as "b" increases "a" decreases. This can be explained, because to take advantage of the high day lighting potential high values of the day lighting aperture are desirable. Fortaleza presented the highest "b" values of the three cities and, therefore, the highest value of energy savings due to its better climatic conditions and day lighting availability.

4. Parametric Analysis for air conditioning savings

In this section it has been analyzed the impact of the use of day lighting in the total annual electricity consumption of a specific commercial building, due to both the air conditioning and the artificial illumination systems. The use of day lighting implies in an increase of the window area, which can contribute to the increasing of the air conditioning load due to the increase of the solar load. On the other hand, the use of day lighting provides a decreasing in the artificial lighting, which is transformed in internal heat gain, contributing to the decreasing of the air conditioning load.

Figure 4 shows the annual total electricity energy consumption without any day lighting strategy, for the four types of glazing shown in Tab. (1) and for various "WWR" ratios (i.e., the ratio between the window and wall area), for the city of Belo Horizonte. Figure (5) shows the annual total electricity energy consumption for the single clear glazing (SC), considering different minimum dimming fractions for various "WWR" ratios, for the city of Belo Horizonte.

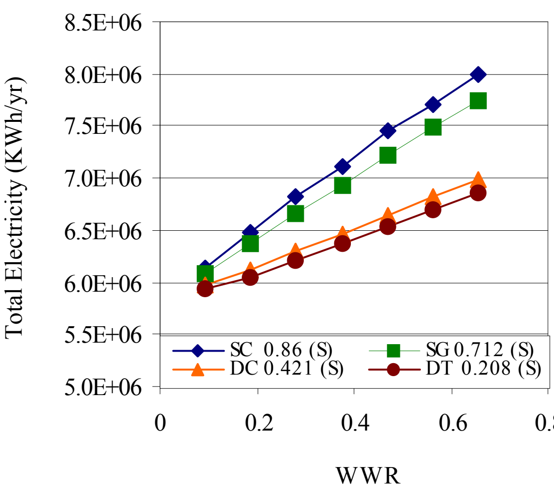

Figure 4. Total annual electricity consumption without day lighting control, for Belo Horizonte.

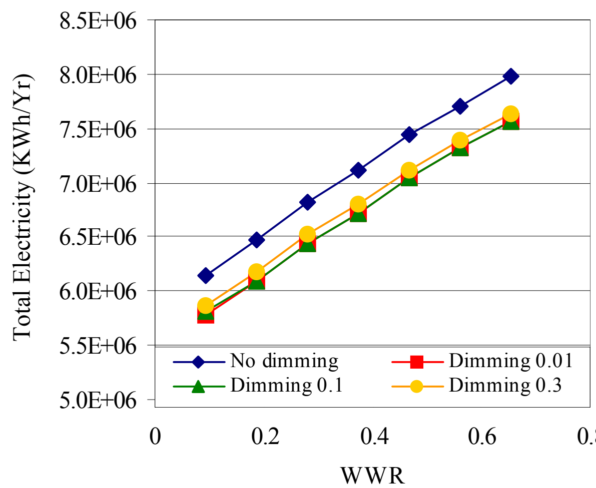

Figure 5. Total annual electricity consumption considering different minimum dimming fractions, for Belo Horizonte.

Figure 4 shows that the total annual electricity consumption increases directly with the "WWR". As the window area increases the solar radiation entering into the building increases and, therefore, more cooling is required causing an increase in the air-conditioning energy consumption. Figure 4 also shows that the total energy consumption is higher for the clear glazing, which shows high values of "SHGF" and visible transmittance.

Figure 5 shows a comparison between the total electricity energy consumption for different minimum dimming fractions. As reference, Fig. 5 also shows the energy consumption without day lighting control. It can be seen that as the minimum fraction decreases the total annual energy consumption also decreases due to the use of day lighting. Figures 4 and 5 do not discriminate the illumination and air conditioning energy consumption.

Figures 6 and 7 show the total annual electricity energy consumption for a single clear gazing, considering different minimum dimming fractions, for various "WWR" ratios, for the cities of Fortaleza e Curitiba, respectively.

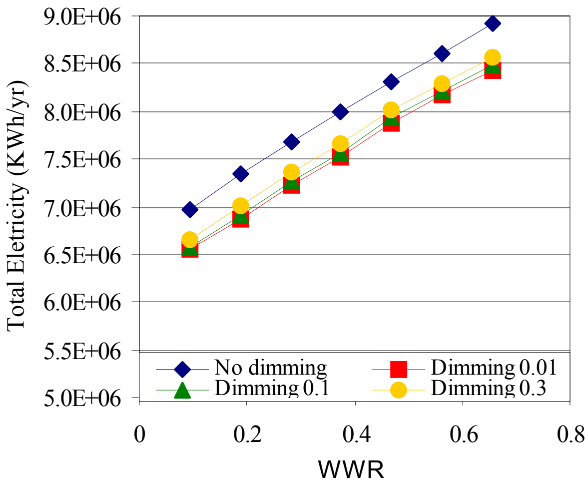

Figure 6. Total annual electricity consumption considering different minimum fractions, for Fortaleza.

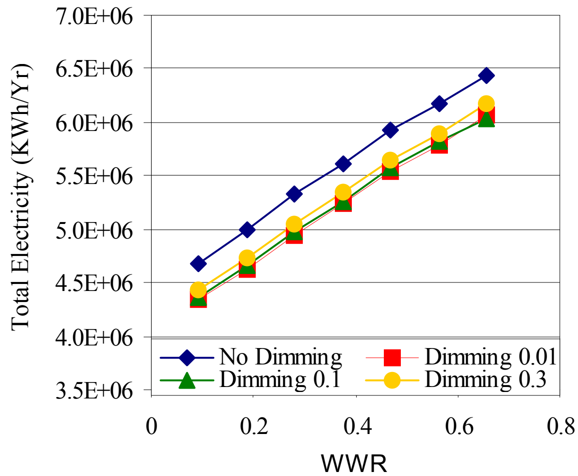

Figure 7. Total annual electricity consumption considering different minimum dimming fractions, for Curitiba.

Figures 6 and 7 show the same behavior of Figure 5. The total annual electricity consumption increases directly with the "WWR". As expected, for all "WWR" the highest total annual energy consumption occurs for the city of Fortaleza, followed by the cities of Belo Horizonte and Curitiba. For all figures 4, 5, 6 and 7, it has been noticed that there is not significant reduction of the total annual electricity consumption when the minimum dimming fractions becomes smaller than 0.1.

Table 4 shows the discriminated values of the annual electricity consumptions and their respective savings for the illumination and air conditioning systems, considering two different "WWR" ratios, for the cities of Fortaleza, Belo Horizonte and Curitiba. For these simulations it has been considered the working period of eight hours per day, twenty days per month. The electricity energy cost was assumed R$0.444/KWh. The energy consumption of the illumination system without day lighting control is 1468308 kWh/year for all the three cities. The annual energy consumption due to the air conditioning system without the use of day lighting control depends on the weather data and is not the same for the three cities. In this simulation the value of the minimum-dimming fraction was equal to 0.01.

Table 4. Annual energy costs and savings for the illumination and air conditioning systems.

Cities	**WWR**	***Illumination System***			***Air Conditioning System***		
		kWh/year	Energy Savings kWh/year	Cost Savings R$/year	kWh/Year	Energy Savings kWh/year	Cost Savings R$/year
Fortaleza	0.1	1211733	256575	**114010.90**	5335140	173478	**77086.16**
	0.7	1171622	296686	**131834.50**	7266462	185206	**82297.58**
Belo Horizonte	0.1	1249374	218934	**97284.86**	4532361	135659	**60281.03**
	0.7	1201987	266321	**118341.60**	6320602	197036	**87554.33**
Curitiba	0.1	1266473	201835	**89686.80**	3075848	130093	**57807.74**
	0.7	1218112	250196	**111176.34**	4841531	119747	**53210.42**

Table 4 shows for all cities a reduction in the annual electricity consumption of the illumination system with the use of a day lighting control system, which generates energy and costs savings. The energy savings increases with the increase of the "WWR" ratios. The annual average energy savings in the illumination system for the cities of Fortaleza, Belo Horizonte and Curitiba were 23.3%, 19.8% and, 18.2%, respectively.

Table 4 shows for all cities a light reduction in the annual electricity consumption of the air conditioning system with the use of a day lighting control system, which generates energy and costs savings (approximately 3% in average). The energy savings decrease slightly for the cities of Fortaleza and Curitiba and increase slightly for the city of Belo Horizonte as a function of the increase of the "WWR" ratios. The annual average energy savings in the air conditioning system for the cities of Fortaleza, Belo Horizonte and Curitiba were 2.9%, 3.1% and, 3.4%, respectively. The annual energy consumptions due to the air conditioning system compared to the total annual electricity consumption (i.e., the sum of the annual electricity caused by the air conditioning and lighting systems) for the cities of Fortaleza, Belo Horizonte and Curitiba are 84%, 81%, and, 75%, respectively. Therefore, it was not observed optimum points for "WWR" for the three Brazilians cities analyzed in this work, because the energy consumption due to the air conditioning systems, in average, is higher than 80% of the total energy consumption. In fact this value can drop a little bit if it is considered other electricity consumption, such as office equipment (i.e., computers, printers, etc.).

5. Conclusions

This work presented the coefficients of a correlation, used to predict electricity savings due to the use of day lighting controllers, for the cities of Fortaleza, Belo Horizonte and Curitba, which are representative of different regions and climates of Brazil.

Parametric analyses were performed for the illumination system taking in account the type of glazing, the site (i.e., the specific climate parameters of the site), and different minimum fractions of dimming controller. The most clear glazing with high values of transmittance and SGHF, the most sunshine city (Fortaleza), and the dimming controller with minimum fraction of 0.1 provided the best results for electricity savings due to the artificial illumination system.

An annual energy analyses it was performed to discriminate the annual electricity consumption due to the air conditioning and the illumination systems. The air conditioning responded for approximately 80% of the total energy consumption (considering lighting and air conditioning). The use of day lighting provided very slight energy savings in the air conditioning system (approximately 3%). No optimum point for "WWR" have been found for the Brazilians cities due to the large requirements for cooling for the specific simulations performed in this work.

6. Acknowledgements

We would like to thank the following people that contributed someway with their support to the development of this work: Dr. Moncef Krarti from the University of Colorado at Boulder, Prof. Dr. Frederico Romagnoli Silveira Lima and Prof. Dr. Marco Aurélio dos Santos Bernardes, both from the Centro Federal de Educação Tecnológica de Minas Gerais.

7. References

ABNT standard, 1980, "NBR 6401 - Instalações Centrais de Ar Condicionado para Conforto – Parâmetros Básicos de Projeto".

ASHRAE Handbook, 1997, "Fundamentals" SI Edition, American Society of Heating, Ventilating and Air-Conditioning Engineers", Atlanta. USA.

CEMIG, 2001, Apostila "Projeto de Prédios Eficientes" e Manual de Procedimento para as Comissões Internas de Conservação de Energia CICE".

ERICKSON P., HILLMAN T., and KRARTI M, 2005, "A Simplified Method to Estimate Energy Day lighting of Artificial Lighting Use from day lighting", Building and Environment, Vol. 40, No. 6, pp: 747-754.

LINO L., SOUZA M, LEITE T. M., PEREIRA F. O. R., 1999, Determinação do Potencial de Aproveitamento da Luz Natural para o Prédio do Núcleo de Desenvolvimento Infantil da Universidade Federal de Santa Catarina, II Encontro Nacional no Ambiente Construído e II Encontro Latino Americano de Conforto no Ambiente Construído.

SOUZA M. B. E PEREIRA F. R., 1995, "Impacto da luz natural no consumo de energia em edificações comercias" III Encontro Nacional no Ambiente Construído e I Encontro Latino Americano de Conforto no Ambiente Construído, pp. 481-486.

SEBRAE, 2002, Apostila "Curso Eficiência Energética nas Micro, Pequenas e Médias Empresas", Energia Brasil.

5. Responsibility notice

José Henrique Martins Neto, Viviane Cristina da Costa Jorge and Ana Angélica Machado Máximo are the only responsible for the printed material included in this paper.