ASSESSMENT OF THE ENERGY SAVINGS POTENTIAL OF DAYLIGHT UTILIZATION AND ITS IMPACT ON A BUILDING ENERGY PERFORMANCE

Hermano Bernardo[1,2], Sérgio Leitão[3], Luís Neves[1,2], and Paulo Rodrigues[1,2]
[1]Institute for Systems Engineering and Computers at Coimbra, Portugal
[2]Polytechnic Institute of Leiria, Portugal
[3]University of Trás-os-Montes and Alto Douro, Portugal

ABSTRACT

This paper aims at determining the energy saving potential that can be obtained by adequate measures and investments through computational simulation, using DesignBuilder/Energyplus software. It presents the simulated values of the impact on the energy consumptions of a building, caused by artificial lighting control systems set to maximize the use of daylight and its effect on the building energy performance labelling, according to recent European and Portuguese legislation changes on this matter.

The work developed was based on a real case-study of a services building located in central Portugal. The basis for the work was a computational model of the building, adequately calibrated and validated using field measurements.

INTRODUCTION

Buildings are responsible for over 40% of the total final energy consumed in European Union (EU) countries. In Portugal, residential and service buildings represents about 60% of electricity produced, and about 30% of the total primary energy (Bernardo, 2009).

The use of daylight in buildings can provide a great energy saving, but it cannot generally meet all of buildings daytime lighting requirements, it will be necessary to install artificial lighting systems to be used whenever the amount of daylight is not enough. In order to save energy it is necessary to install control systems which make it possible to adjust the artificial lighting levels according to daylight levels and the utilization of the building.

Building energy simulation tools provide accurate predictions of the energetic performance of buildings and thermal comfort of its occupants, allowing an evaluation of the impact of improvement measures, in order to support the choice of the most effective measures (Maile et al., 2007).

The prediction of energy consumption in buildings, through computational simulation, is rarely very precise. The accuracy of any simulation result always depends on the accuracy of input data. Normally, it is necessary to validate the results obtained by simulation through the comparison with measured data of energy consumption, achieved through energy audits to the building, calibrating the models with the present measured values.

BUILDING ENERGY CERTIFICATION IN PORTUGAL

The present work follows the adoption of a number of EU directives on the evaluation of energetic performance of buildings and consequent certification. As a consequence of EU Directive 2002/91/CE, published on the 16th December, and also “Decreto-Lei n.º 78/2006” (SCE, 2006), the certification system “Sistema Nacional de Certificação Energética e da Qualidade do Ar Interior nos Edifícios” (SCE) was created, in Portugal.

SCE sets a certification model for small services buildings, or fractions of buildings dedicated to services, with net surface equal or under 1.000 m^2, and a HVAC system which thermal power, corresponding to the larger of heating or cooling power, exceeds 25 kW. SCE is also applicable to service buildings with a net surface of over 1.000 m^2 (or 500 m^2, in the case of shopping centres and heated swimming pools) whether there is a HVAC system or not. The energy class of a building will be determined by its typology (or weighing of a number of typologies), in contrast with the Energy Efficiency Index (IEEnom), determined by dynamic simulation based on the reference profiles defined by the “Anexo XV” appendix of (RSECE, 2006). The Reference Energy Efficiency Index (IEEref) is the value set by “Anexo XI” appendix of (RSECE, 2006), also according to typology, or weighing of typologies.

The energy class of a building follows a 7+2 class system (A+, A, B, B-, C, D, E, F and G), where the A+ class is given to the buildings with the best energy performances, and G to the worst energy performances.

On new buildings, admitted energy classes are only A+ to B-, whereas existing buildings may naturally present any of the defined energy efficiency classes.

METHODOLOGY

The basis for this work were the blueprints of the building, the building’s energy bills over the time window considered (June 2007 to May 2008), and the energy consumptions characterization obtained through measurements, which were also used to calibrate the computational model developed at this instance.

Due to the high potential of natural lighting usage during sunlight hours, it was simulated the use of lighting sensors associated with dimmers, in order to adjust artificial lighting according to the natural lighting available at each moment.

The conversion factors to primary energy used are the following, according to Portuguese norm (RCCTE, 2006): 0,290 kgoe/kWh for electricity and 0,086 kgoe/kWh for natural gas, parameters defined due to the energy mix of the country.

CASE-STUDY

The building selected as the case study for this work is the Canteen 3, Campus 2 of the Polytechnic Institute of Leiria. It was built in 2005.

The building has a total surface of approximately 1487 m2. It has a rectangular geometry, and is composed of two floors (ground floor and first floor), each 3,2 metres high. The meals hall, the kitchen and logistic support areas are located on the ground floor. On the first floor there is a restaurant a la carte, a cafeteria and other logistic areas.

The main façade of the building faces, predominantly, South-East.

In order to characterize the building's lighting system, a survey of the number of luminaries and lamps, their control systems, the technology used and the lighting level of each room was performed. The survey was performed as an energy audit, also aiming to evaluate existing lighting systems efficiency and detect possible improvements, both towards lower energy consumption and improvement on visual comfort to the users.

An approximate total of 14,3 kW of electric power for lighting is installed in the building, mainly divided by four types of lamp. Tubular fluorescent T5-type lamps are predominant, representing 47,5% of installed power. Also tubular fluorescent lamps, T8-type, represent 23,9%; compact fluorescent lamps amount to 19%; and high-pressure sodium vapor lamps amount to 9,1%.

Building envelope

Table 1 shows the characteristics of building envelope and the value of heat transfer coefficient, U, based on ITE50 publication (Santos et al, 2006).

Table 1
Building construction specification

ELEMENT	U [W/m^2.°C]
External wall	0,50
Ground floor	2,50
Flat roof	1,60
Pitched roof	0,85

The roof is constituted by metallic sandwich panels, with thermal insulation (XPS).

Glazing

The heat transfer coefficient of glazing is shown on Table 2. This value was calculated trough ITE50, supported by software CALUMEN, which is distributed by glazing manufacturer Saint-Gobain.

Table 2
Building glazing specification

GLAZING DESCRIPTION	U [W/m^2.°C]
Double glazed aluminum window (6+10+4) mm	3,74

COMPUTATIONAL MODEL

The building energy simulation for the case study building was performed using the DesignBuilder graphical interface to the EnergyPlus software.

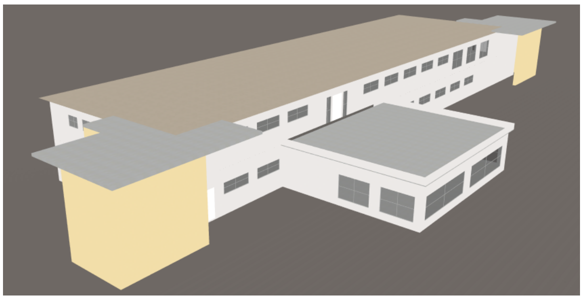

Figure 3 A view of building 3D Model (South).

For the construction of the building model, which was used as the base model representing the existing building, a set of parameters had to be defined. Amongst these, highlights are on the utilization and working hours diagrams, 24 hours a day, for lighting, occupation, equipments, air renewals, ventilation equipments, heating and cooling temperatures (Roriz, 2006).

Weather data

In Portugal, the climate can have three types of influences: Atlantic influence, Mediterranean influence and Continental influence. The climate zone determination was based on weather information of the country and the existing legislation, which defines a division of portuguese territory into three Winter climatic zones (I1, I2 e I3) and three Summer climatic zones (V1, V2 e V3).

The climate file used to the work was the Coimbra's climate file, in International Weather for Energy Calculations (IWEC) format, which is, at the moment, the most similar and near to Leiria. The file is needed so that the simulation software generates the weather dependences in building energy consumption.

Geometry definition

The beginning of the model construction consists in the definition of the building geometry. At this stage the building typology is defined with the required simplifications in order to preserve the essential of characterisitics of the building.

In the present case-study, it was necessary to do a set of simplifications in geometry definition, grouping some physical divisions in a single equivalent thermal zone. For that, it was considered areas with the same internal loads, similar sunlight and the same nominal usage patterns. So, the studied building was splitted into 16 different thermal zones (Figure 1 and Figure 2).

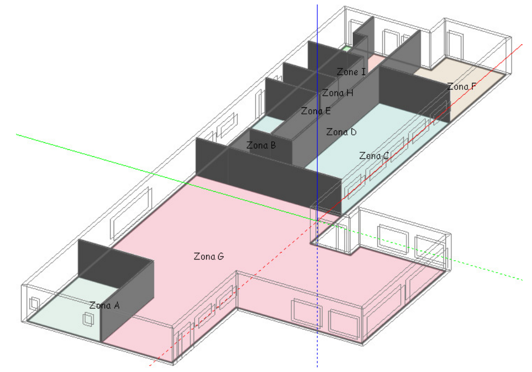

Figure 1 Zones of the Floor 0

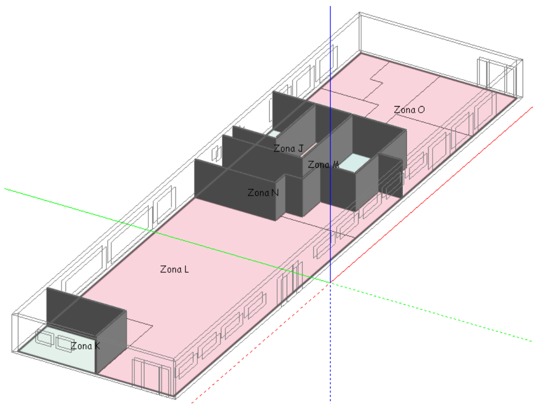

Figure 2 Zones of the Floor 1

Other definitions

The indoor comfort conditions have been set by (RCCTE, 2006), considering an air temperature of 20ºC for the heating season, and an air temperature of 25ºC with 50% relative humidity for the cooling season.

Infiltration rate and/or fresh-air requirements were defined to ensure the minimum fresh-air requirements listed in "Anexo VI" appendix of (RSECE, 2006).

RESULTS

At an initial stage, it was necessary to calibrate the model through a dynamic simulation of the total energy consumption (by energy form) and the disaggregation of such consumptions by final use, comparing these values to data collected from the energy audit measurements of real energy consumption.

To perform this simulation it was considered that the building has a natural gas fueled boiler, with an efficiency of 92% for heating. The distribution of HVAC system is made by 2 pipes until Air Handler Units (AHU), where the heated air is after distributed by ducts through a system of variable air volume (VAV).

In the process of creating and adjusting such a model, the building envelope, the climatization system, the distribution of internal loads and the utilization patterns were the input data to software DesignBuilder.

After computational model calibration by comparison with data gathered through energy audit, were obtained the values shown on Table 3.

Table 3
Comparison between annual energy consumptions

ENERGY	MEASURED [kgoe]	SIMULATED [kgoe]	DEVIATION [%]
Electricity	57.982	52.942	-8,7
Natural gas	23.205	24.455	5,4
Total	81.187	77.397	-4,7

Comparing the values obtained through computational simulation with real measurements, it is patent that, in terms of electricity consumption, the simulated values are lower than the measured values in 8,7% and, in what concerns to natural gas consumption, it is shown that simulated values are higher than the measured values in 5,4%. Globally, there is a deviation of 4,7% on total anual simulated energy consumptions comparing to total anual measured energy consumptions.

According to Portuguese Energy Agency (ADENE) recommendations, in what concerns to energy certification regulations, the difference between the dynamic simulation energy consumptions shouldn't have a deviation higher than 10% comparing to those obtained through energy audit. So, the obtained results were considered satisfactory, validating the computational model to the real situation.

Base case simulation

The annual energy consumptions, as obtained through simulation of the building model, applying real occupation and utilization patterns, are presented in Table 4.

Table 4
Energy consumption – base case

ENERGY USAGE	ELECTRICITY [kWh]	THERMAL ENERGY [kWh]	TOTAL [kgoe]
Lighting	31.355	0	9.093
Equipments	144.314	54.177	46.510
Heating	0	55.587	4.780
Others	6.888	174.599	17.013
TOTAL	182.557	284.363	77.397

Looking at Table 4, it is patent that, under these conditions, the building has a total primary energy consumption of 77.397 kgoe.

The chart in Figure 4 shows the disaggregation of annual total primary energy consumptions by final use.

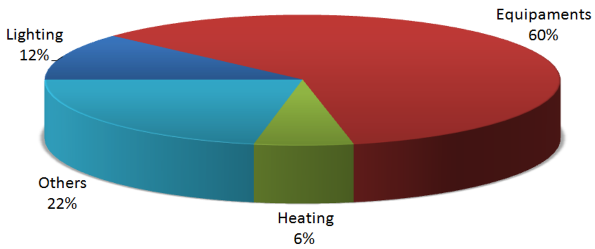

Figure 4 Energy consumptions disaggregation

Simulation of the case-study with lighting systems control

The annual energy consumptions, as obtained through simulation of the building model with lighting systems control, applying real occupation and utilization patterns, are presented in Table 5:

Table 5
Energy consumption – base case with lighting systems optimization

ENERGY USAGE	ELECTRICITY [kWh]	THERMAL ENERGY [kWh]	TOTAL [kgoe]
Lighting	23.494	0	6.813
Equipments	144.314	54.177	46.510
Heating	0	57.851	4.975
Others	6.888	174.599	17.013
TOTAL	174.696	286.627	75.312

Looking at Table 5, it is patent that, under these conditions, the building has a total primary energy consumption of 75.312 kgoe.

The chart in Figure 5 shows the disaggregation of annual total primary energy consumptions by final use.

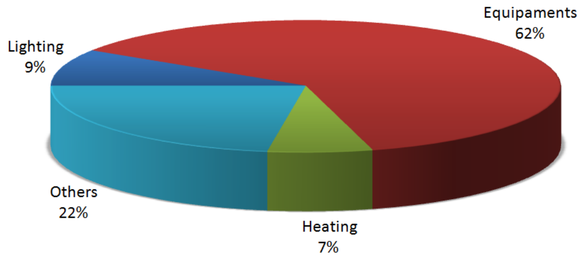

Figure 5 Energy consumptions disaggregation

Comparative analysis of results

Comparing the results of both simulations performed, using the real utilization and occupation patterns, there are visible differences in the obtained results.

Table 6 presents a comparison between the base case, with no optimization system, and the optimized case, with illuminance sensors associated with dimmers.

Table 6
Comparison of results – electricity

ENERGY USAGE	BASE CASE [kWh]	BASE CASE OPTIMIZED [kWh]	REDUCTION [%]
Lighting	31.355	23.494	25,1
Equipments	144.314	144.314	0,0
Others	6.888	6.888	0,0
TOTAL	182.557	174.696	4,3

It can be seen that there is a reduction of electric energy consumption, mainly due to the reduction of lighting consumptions, which is associated with a reduction of the energy bill.

The savings on electricity amount to 4,3% of total electricity consumption. However, the reduction on artificial lighting systems is quite significant (25,1%).

In terms of total primary energy, results obtained are presented on Table 7:

Table 7
Comparison of results – primary energy

ENERGY USAGE	BASE CASE [kgoe]	BASE CASE OPTIMIZED [kgoe]	REDUCTION [%]
Lighting	9.093	6.813	25,1
Equipments	46.510	46.510	0,0
Heating	4.780	4.975	-4,1
Others	17.013	17.013	0,0
TOTAL	77.396	75.311	2,7

The energy consumption of the heating systems has a slight increase (4,1%) due to the reduction of the thermal load inside the building but, globally, the energy consumption shows a decrease.

It is patent that, despite the significant reduction of energy consumptions of artificial lighting (25,1%), this represents a sole saving of 2,7% on the total energy (electrical and thermal) consumption of the building.

Energy savings potential

From the results stated previously, the energy savings resulting of the optimization of artificial lighting systems, thus maximizing the resource to natural lighting, is presented on Table 7:

Table 7
Annual savings potential

	ENERGY SAVING [kgoe]	COST REDUCTION [€]
Repercussion on electricity consumption	2.280	708
Repercussion on natural gas consumption	-195	-121
TOTAL	2.085	587

Based on obtained results, it is visible that, although there is a reduction of electricity costs of 708€, the yearly cost of natural gas actually increases by 195€, due to the decrease of the thermal load of the building in the heating season.

Globally, there is an energy saving potential of 2.085kgoe, which means a total cost reduction of 587€.

Considering the investment cost of approximately 3.000€ associated with the installation of the control and optimization system, and the cost reduction calculated, the return period of the investment is approximately 5 years.

Implementing this simple yet effective optimization measure would cause a reduction of CO2 emissions of 3.172 kgCO2e, due only to energy savings.

BUILDING ENERGY LABELLING

The method used to determine the IEEnom of a large existing building followed several approaches and stages, in order to ensure the reliability of the results obtained.

The simulation of nominal consumptions followed, where the characteristics of the building, the power density for artificial lighting and HVAC systems are kept, replacing the actual use profiles (for occupation, equipments and lighting) with the reference profiles and densities, according to the “Anexo XV” appendix of [8]. For this simulation, a climate data file, with the available standard climate information, should also be used. The nominal energy needs also have to be computed, contemplating the different energy forms, according to nominal profiles, for the various end uses.

In order to evaluate the energy performance and determine the efficiency class, several simulations were performed under different conditions.

Base case

Results of a thorough dynamic simulation, with nominal profiles, after converting final to primary energy, are summarily presented on Table 8:

Table 8
Energy consumption – reference case

	HEATING	COOLING	OTHERS
Energy consumption [kgoe/m^2]	35.217	20.078	113.001

The IEEnom index for this building is 104,89 kgoe/m^2, which means the building has Class B efficiency, under these circumstances.

Maximization of the use of daylight

If the building is equipped with systems leading to the maximization of the use of natural lighting, such devices should influence the simulation results for nominal conditions (Bernardo, 2010).

Therefore, a new simulation was performed, using the reference usage patterns set in the “Anexo XV” appendix of portuguese norm (RSECE, 2006), but using lighting sensors associated to dimmers, responding to the variations of natural lighting. This sort of management and automatic control systems often represents an interesting solution to a more rational use of energy for lighting and should therefore be accounted for in the calculations of specific global consumptions of a building under nominal conditions.

The results of a dynamic simulation including this system are presented on Table 9:

Table 9
Energy consumption – maximizing the use of daylight

	HEATING	COOLING	OTHERS
Energy consumption [kgoe/m^2]	36.049	19.737	106.411

The IEEnom is then 100,59 kgoe/m^2, which is lower both than the reference case and the building is no longer a Class B building, but an Energy Efficiency Class A building.

A lighting control system that maximizes the use of natural lighting causes such a reduction of the IEEnom index as to clearly change the building to a higher efficiency energy class, the building becoming a Class A building.

CONCLUSION

The use of computational simulation tools proves to be a big contribution to the evaluation of energy performance of buildings and the prospect study of the impact that possible efficiency improvements may have on it.

During the winter, and assuming thermal loads are lower than the losses, artificial lighting systems can be beneficial and should always be taken into account when performing simulations and dimensioning climatization systems, as they represent a thermal load which contributes to the building's heating. During the summer, lighting systems should also be considered, this time because they represent an extra load that must be removed by the cooling system, in case of its existence.

Results show that the maximization of daylight utilization in buildings due to the implementation of artificial lighting management and control actions is a very interesting option to promote a more efficient use of energy and to improve the energy performance of a building of these characteristics.

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