Building energy analysis of Electrical Engineering Building from DesignBuilder tool: calibration and simulations

J Cárdenas\(^1\), G Osma\(^1\), C Caicedo\(^1\), A Torres\(^1\), S Sánchez\(^1\), and G Ordóñez\(^1\)

Department of Electrical, Electronic Engineering and Telecommunications, Industrial University of Santander, Cra. 27 Calle 9, Bucaramanga, Colombia.

E-mail: german.osma@correo.uis.edu.co

Abstract. This research shows the energy analysis of the Electrical Engineering Building, located on campus of the Industrial University of Santander in Bucaramanga – Colombia. This building is a green pilot for analysing energy saving strategies such as solar pipes, green roof, daylighting, and automation, among others. Energy analysis was performed by means of DesignBuilder software from virtual model of the building. Several variables were analysed such as air temperature, relative humidity, air velocity, daylighting, and energy consumption. According to two criteria, thermal load and energy consumption, critical areas were defined. The calibration and validation process of the virtual model was done obtaining error below 5\% in comparison with measured values. The simulations show that the average indoor temperature in the critical areas of the building was 27°C, whilst relative humidity reached values near to 70\% per year. The most critical discomfort conditions were found in the area of the greatest concentration of people, which has an average annual temperature of 30°C. Solar pipes can increase 33\% daylight levels into the areas located on the upper floors of the building. In the case of the green roofs, the simulated results show that these reduces of nearly 31\% of the internal heat gains through the roof, as well as a decrease in energy consumption related to air conditioning of 5\% for some areas on the fourth and fifth floor. The estimated energy consumption of the building was 69 283 kWh per year.

1. Introduction

The residential and commercial buildings have energy consumption between 20\% and 40\% of total world energy consumption [1]. This has become a problem due to increased energy demand and related emissions. In order to reduce consumption in buildings, initially it is required to understand the energy performance of the building. This task is complex and therefore demands the use of energy simulation tools [2].

In the tropics energy performance of a building is highly influenced by the outside weather conditions [3]. High values of temperature, relative humidity, and solar radiation are characteristic of cities like Bucaramanga. Such conditions can lead to heating of the interior spaces, which results in significant increases in cooling loads and reduce the sensation of thermal comfort of the occupants[3]--[8].

Currently, the Industrial University of Santander studies the energy performance of the Electrical Engineering Building for warm tropical weather conditions. This building incorporates energy-saving strategies such as solar tubes, green roof, natural ventilation, natural lighting, and highly efficient hybrid systems (lighting and air conditioning). Such infrastructure allows conducting studies aimed at
identifying factors, which influence significantly on the energy performance and user comfort, especially in areas exposed to critical conditions of environment, electrical charges and occupation.

Considering the above, the objective of this research is to carry out an energy analysis of the Electrical Engineering Building through simulations obtained through DesignBuilder.

This document consists of three sections, Section II describes the process of obtaining and validating the virtual model of the building, Section III presents the main results of the energy simulations, and Section IV exposes the conclusions about energy analysis.

2. Methodology
The methodology for this research is based on process modeling and energy analysis of buildings in energy simulation tools as DesignBuilder [9]. Initially, a description of the building under study is performed in order to present the most relevant features of the building have been taken into account in the energy modeling. Subsequently, the process of virtual modeling and calibration through environmental measurements is shown. Finally, a compilation of energy simulations carried out for calibration and energy analysis of the virtual model is shown.

2.1. Building under study
Electrical Engineering Building - EEB is located on the central campus of the Industrial University of Santander in Bucaramanga - Colombia, a region of tropical climate. The building has an area of 2700 m$^2$ distributed in five floors. The building includes spaces for classrooms, study rooms and offices. The ambient temperature in Bucaramanga varies between 24°C and 30°C and annual rainfall levels are close to 1279 mm. Figure 1 shows the building.

![Figure 1. South façade of the Electrical Engineering Building.](image)

The envelope of the building is composed of outer walls in concrete, brick and drywall. All areas of significant occupation of the building they have glazing areas over 40% in the walls of the facade, allowing the use of natural ventilation and lighting. Passive strategies for sustainable construction like green roof and solar tubes were implemented in the flat roof of the building. Hybrid systems (lighting and air conditioning) were defined in some areas of the building.

2.2. Virtual model of building
The virtual model of the building in energy simulation tool DesignBuilder consisted of geometric modelling and incorporating data model. The geometric model was carried out in four stages: generation blocks through DXF plans; tracing interior partitions to create zones; definition of windows, doors and other openings; and modelling of architectural details and buildings surrounding area. Modelling solar tubes required a special approach for including in model. The whole geometric model of EEB is shown in Figure 2.
Figure 2. Geometric model of Electrical Engineering Building created in DesignBuilder.

Filling model data in DesignBuilder is performed considering five data categories: activity, constructions, openings, lighting and HVAC systems. Activity data are related to the use of zones and conditions of users comfort. The materials and thicknesses of the various components of the envelope were defined in the construction data category. The characteristics of the windows and doors were taken into account in the openings data category, of the same way that lighting and HVAC information.

2.3. Model calibration
The calibration process involves the identification of critical zones, environmental variables monitoring, and the validation of the model.

2.3.1. Identification of critical zones. The identification of critical zones was carried out taking into account criteria how: occupation, artificial lighting loads, operating loads of equipment, ventilation and infiltration loads, and solar radiation loads. A quantitative assessment of the impact on energy consumption and thermal comfort have the criteria mentioned above was carried out for all building spaces. Aspects such as the number of people, weekly time intensity and metabolic activity were considered for the evaluation of the occupation criteria. The installed power lighting and power equipment in each area were taken into account in the evaluation of lighting and equipment loads. For ventilation and infiltration loads were considered the presence in the spaces of windows, sun breakers, vents and heat extractors. Finally, the location of the areas was taken into account in assessing the loads associated with solar radiation. Table 1 shows the areas identified as critical zones.

Table 1. Critical zones of Electrical Engineering Building.

| Floor | Zone                                           |
|-------|------------------------------------------------|
| 1     | Group study room and Single study room         |
| 4     | Classroom 402 Classroom 404, and 406 Classroom.|
| 5     | Student waiting room, Meeting room, Waiting room, File area and project and service zone. |

2.3.2. Environmental variables monitoring. The evaluation of the accuracy of the results of the simulations are based on the measurement of environmental variables such as air temperature, relative humidity, air velocity, and daylighting level in each critical zone. The measurements were performed between 8:00 am and 6:00 pm from Monday to Saturday during June of 2014. Table 2 shows the average values measured for each of the variables mentioned above.
Table 2. Mean values measured air temperature, relative humidity, air velocity and level of daylighting in each of the zones identified as critical.

| Zone                      | Air temp. [°C] | Relative humidity [%] | Air velocity [m/s] | Average level of daylighting [lux] |
|---------------------------|----------------|-----------------------|--------------------|-----------------------------------|
| Project and service zone  | 25.7           | 69.6                  | 0.2                | 2213.2                            |
| Student waiting room      | 27.1           | 67.3                  | 0.1                | 1742.2                            |
| File area                 | 26.2           | 67.5                  | 0.1                | 1216.1                            |
| Meeting room              | 25.8           | 68.8                  | 0.3                | 797.1                             |
| Waiting room              | 26             | 69.4                  | 0.3                | 1673.8                            |
| Classroom 402             | 26.5           | 69.1                  | 0.2                | 1910.8                            |
| Classroom 404             | 26             | 64.9                  | 0.6                | 2907.6                            |
| Classroom 406             | 26.8           | 69.6                  | 0.2                | 1106.6                            |
| Group study room          | 26.7           | 68.8                  | 0.3                | 959.9                             |
| Single study room         | 26.9           | 70.1                  | 0.1                | 586.2                             |

The measured value of total annual energy consumption of the building was also considered. This corresponds to 48 200 kWh per year.

2.3.3. Validation of the model. The validation process consisted of a comparison between measured and simulated values of air temperature, relative humidity, air velocity, and daylighting level and energy consumption.

Differences minor that 5% were found in the most of the critical zones. This value suggests that the virtual model of the Electrical Engineering Building is acceptable for use in energy analysis, the main objective of this research. The greatest differences were found in the area of higher occupancy (Group study room) for the air temperature and air velocity with 12.9% and 7.14%, respectively. In the case of relative humidity, the difference found was close to 0.2%.

The simulated annual energy consumption was close to 50,000 kWh, this value is approximately 4% higher than the measured value. A tuning process carried out with respect to occupation and use of systems and equipment, in order to mitigate the percentage differences.

2.4. Simulation plan
Two sets of simulations mainly comprise the analysis of the energy performance of the building: Preliminary simulations and energy simulations. Preliminary simulations were done for calibrating the virtual model, from which air temperature, relative humidity, air velocity, and daylighting level were obtained for comparison with the measured values. The energy simulations were used to estimate the energy consumption of the building and the heat gains.

3. Analysis of results
In order to describe the energy performance of the building, the results of the energy simulations related to thermal comfort, indoor heat gains and the impact of energy saving applications were analyzed.

3.1. Thermal comfort
Average annual values of temperature and relative humidity were taken into account in establishing the internal thermal conditions in the main building critical areas. According to them, only the critical zones with air conditioning have thermal comfort conditions all year. The most unfavourable
environmental conditions were found for Group study room and Classroom 402, where the air temperature has average annual values of 30.31 °C and 29.96 °C. In the case of relative humidity, an average annual value of 67% was found.

The thermal conditions of the building are characterized in DesignBuilder using thermal comfort indices. According to these, the most representative critical zones without air conditioning have a thermal indoor environment among slightly hot and very hot (values between 1 and 3 on the scale of comfort indices) as shown in Figure 3.

![Figure 3](image-url)  
**Figure 3.** Thermal comfort indices for the most representative critical areas of EEB.

3.2. **Internal heat gains**
An analysis of the results of internal heat gains was conducted to identify the possible causes of thermal discomfort inside the building.

The heat through the glazing and heat associated with occupancy were the most significant internal sources of heat according to the simulations. These represent on average 68% and 17% of total internal gains, respectively. This makes them the main causes of thermal discomfort in areas such as Study group room and Classroom 402. Computers represent another important source of heating in areas, such as in Study room and Modular office with 14% and 26%, respectively.

3.3. **Effects of solar tubes on daylighting**
The effect of solar tubes on daylighting was analyzed in two critical classrooms located on the fourth floor of the building. The average daily value of the level of daylighting was established, taking into account partly cloudy sky conditions. An increase of 12.52% in the level of daylighting was found in the Classroom 402 due to solar tubes. In the case of the Classroom 401, the increase was around 40% due to a 100% increase in the amount of solar tubes present in this area with respect to Classroom 402. Another result showed that 58% of the areas susceptible to glare are areas of movement of persons.

3.4. **Effects of green roof on the building energy performance**
In order to demonstrate the effect of green roof on the building energy performance, the modular offices zone (5th floor) was selected. This area has the largest area of green roof exposed to solar radiation. According to the simulations, the green roof reduces approximately a 31% the value of internal heat gains associated to the cover with respect to a situation without green roof. The existing green roof reduces the annual energy consumption of the Classroom 401 near to 5%.

4. **Conclusions**
According to the process of modeling and simulation of EEB, DesignBuilder is a suitable energy simulation tool for analyzing buildings in the tropical environment. The simulation results show that
natural ventilation, solar radiation and occupation have direct influence on the energy performance of the building.

The results of thermal comfort showed that the most unfavorable environmental conditions were presented in the Group study room and Classroom 402. This behaviour is due to internal heating of the space by the action of solar radiation on the glazing, the heat radiated by the occupation and computers. Although most critical areas present conditions of thermal discomfort during most of the year, the natural ventilation minimizes the perception of those conditions.

Satisfactory levels of daylighting were found in every critical area, particularly those located on the upper floors. Solar tubes increase approximately 33% the level of daylighting. Of all the zones analysed, only 9% of them have glare conditions.

Green roof reduce a 31% of internal heat gains associated with the cover for administrative area of the building (5th floor); whilst, it produces near to 5% of energy savings in the Classroom 401.

The simulated energy consumption was approximately 50 000 kWh per year; this differs from the measured value at only 4 %.

5. References
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