Simplified Building Simulation Tool Applied in the Early Stages of Building Design and Energy Labeling

Mauricio Nath Lopes (mauricio.nath@ifsc.edu.br)
Federal Institute of Santa Catarina, Brazil

Lucila M. S. Campos (lucila.campos@ufsc.br)
Federal University of Santa Catarina, Brazil
Department of Production Engineering and Systems

Roberto Lamberts (roberto.lamberts@ufsc.br)
Federal University of Santa Catarina, Brazil
Department of Civil Engineering

Abstract
This paper describes a simplified building simulation tool developed for evaluating the energy efficiency of commercial buildings according to the Brazilian labeling program. The paper describes the tool and also evaluates its potential when introduced into the design process of the efficient buildings.

Keywords: building simulation, design, energy efficiency.

Introduction
In Brazil, the contribution of residential, commercial and government buildings accounted for 47.6% of total electricity consumption in 2012, with the commercial and government sectors consuming 24% (Ben 2013). Considering the economic stability, high urbanization ratio and the increasing services sector expansion, it is expected that this raising scenario continue.

Labeling is viewed as an effective tool for reducing energy consumption by buildings. According to the World Energy Council (World Council 2004), labeling and minimum energy efficiency criteria are the top-performing options for obtaining fast improvements. Moreover, Brazil’s National Institute of Metrology, Standardization and Industrial Quality - INMETRO (Inmetro 2007) notes that when labeling is associated with performance goals, it constitutes an important tool for reducing energy consumption in Brazil, through encouraging technological upgrades in the fabrication of equipment earmarked for the domestic market, boosting the supply of good to consumers with better energy performances and consequently raising their quality to international levels (Batista et al. 2011).

In Brazil, the Quality Technical Requirements for Energy Efficiency Level of the Commercial, Service and Public Buildings - RTQ-C (Inmetro 2010), released in 2009 as part of the Brazilian Labeling Program, specifies technical requisites and the methods to classify commercial buildings regarding their energy efficiency. The Regulation was based on the ASHRAE Standard 90.1 (Ashrae 2007) and includes requisites for building envelope, lighting and HVAC systems.
The buildings in the Brazilian labeling process are classified according to five possible levels of efficiency (from label A - more efficient, to E - less efficient). The RTQ-C contains two different methods for building rating: the prescriptive method and the simulation method.

The prescriptive option establishes limits of physical properties of envelope materials and components and equipment efficiency. In the prescriptive method, the building envelope performance, the lighting system efficiency and the air conditioning efficiency are evaluated separately and classified into one of five possible levels of efficiency. Then, the general classification of the building is determined considering the following weighting: building envelope (30%), lighting system (30%) and air conditioning system (40%). There are bonuses that can increase the building’s overall energy efficiency level.

Obtaining the building efficiency level by the simulation method consists in comparing the performance of the proposed (real) building with a similar building (reference) whose features comply with the desired efficiency level. Therefore, two models must be built: a) the model representative of the real building (in accordance with the proposed project) and, b) the reference model (in accordance with the desired efficiency level). It must be proven the annual energy consumption of the proposed project is equal or lesser the annual consumption of the reference building. The simulation method in the Brazilian labelling process is thoroughly described by Lopes et al. (2011).

Due to its complexity, performing a simulation for determining building energy efficiency is rather cumbersome for most people because it requires specific knowledge. Therefore, simulation in Brazil is nowadays still limited to universities and a few consultant companies. For this reason, the simulation method has been used in less than 5% of total labeled buildings in Brazil.

The present paper describes the computational tool S3E (Simulator of Energy Efficiency in Edifices) that provides easy access to engineers, architects and designers to simulate commercial buildings energy efficiency, especially regarding the aspects related with the Brazilian labeling process.

**Theoretical Review**

In recent decades, a wide range of building simulation softwares became available. The improvement of building simulation into a recognized and indispensable discipline for all professional, involved in the design, engineering, operation and management of buildings has now become the imminent challenge. There are two key aspects that dominate this evolution process: i) attaining an increased level of quality assurance and, ii) offering efficient integration of simulation expertise and tools in the overall building process (Augenbroe 2001).

However, despite the great potential identified for energy simulation, currently it has been used only for analysis of energy performance, rather than being used for the design of a building envelope (Yi et al. 2012).

The envelope of a building has a significant impact on thermal comfort and sizing of the HVAC system. In most cases, architects design the envelope, which is then forwarded to the designers of the HVAC system to develop it (Ellis et al. 2001). Thus, the thermal analysis is performed on a stage that most design decisions have already been taken (Holm 1993). This sequencial design can potentially lead to buildings that are energy inefficient and require large HVAC systems.

Most of simulations tools are not in tune with the architects approach and not suitable for early design stages when major decisions are made (Weytjens et al. 2010). These tools are
complex and consume a significant time. In addition, they often require detailed information of building, unavailable in the initial design phase. The detailed input data is a major limitation of current building energy simulation tools (Weytjens et al. 2010).

There is a lack of parametric design software that enable the analysis of the performance of the building in the early stages of architectural design to assist in the decision-making process (Toth et al. 2011).

Some simplified models have been proposed to analyze the energy performance of buildings. Ellis et al. (2001) developed a simplified tool for architects employ the analysis of the thermal performance of buildings in the early stages of the design envelope. Nielsen (2005) developed a simplified dynamic simulation tool with few input data, to evaluate the energy consumption and thermal comfort of buildings for use in the early stages of architectural design. Ourghi et al. (2007) developed a simplified method to estimate the impact of office buildings geometry on energy consumption, directly correlating the form factor (relative compactness) and consumption. Petersen et al. (2010) proposed a method which consists of a program that uses simulation software to make performance predictions from variations of user-defined parameters. Yi et al. (2012) created a methodology in which architects can generate geometry optimized energy from the energy simulation results. Granadeiro et al. (2013a) developed an indicator of energy performance for residential buildings (Envelope-Related Energy Demand – ERED). And also Granadeiro et al. (2013b) developed a methodology that involves a flexible system design, where alternative geometries are generated, and energy demand is calculated by employing energy simulation.

But surveys indicate that most architects who use building simulation softwares (ECOTECT, HEED, Energy 10, Design Builder, eQUEST, DOE-2, Green Building Studio, IES VE, Energy Plus and Energy Plus-OpenStudio) in the design practice are much more concerned with usability and information management of interface and the integration of intelligent design knowledge-base (Attia et al. 2009). These two issues are the main factors for identifying a building simulation program as “architect friendly”, according to Attia et al. 2009.

The S3E tool developed by the Laboratory of Energy Efficiency in Buildings (LabEEE) of Federal University of Santa Catarina will be presented below. This web-based and user-friendly tool aims at popularizing the use of simulation for commercial building energy efficiency in Brazil. The main goal is that construction market professionals and users without any specific technical knowledge on simulation are able to perform simulations in a quick and straightforward way. The tool can be used to define the level of efficiency and to optimize the design of the building regarding energy efficiency.

The S3E Tool

The computational tool S3E allows any user through the World Wide Web to freely access it (www.s3e.ufsc.br), where one can select many items that characterize the commercial building, such as: dimensions, constructive materials, use, type of the air-conditioning system etc. With this data, the simulation runs in the server. When it is complete, a notification message is sent to the user's e-mail address to let one know that the simulation results are available.

The user is able to verify the energy efficiency level of the building under analysis (with a level ranging from A to E), as well as assess the influence of changing specifications. The S3E user can keep all ones simulation data stored in the server, reedit and reuse customized data, because private access is granted by username and password.
The S3E tool uses EnergyPlus as simulation software. EnergyPlus is developed by the United States Department of Energy (DOE) in cooperation with many research centers around the world, and it has been approved by BESTEST.

The S3E tool functioning is sketched on Figure 1. The user inputs the proposed building data. The data volume provided by the user is significantly less and in higher level than the data required for regular simulation models, therefore it is necessary additional information (default values). Using this set of data, five EP input files (IDF) are created, one regarding the proposed building model and four regarding the reference building models (Levels A, B, C and D). Each file is simulated on EP and the respective annual energy consumption is acquired. The comparison among the results allows to classify the building energy efficiency level achieved by the proposed model according to the Brazilian Energy Efficiency Level of the Commercial, Service and Public Buildings.

![Figure 1 - S3E workflow schematic](image)

**a) Web interface and Server**

The interface of the computational tool has two modules: the data input module and the simulation management module.

The input data module is where building information is requested to the user. This module allows that users, during their first contact with the tool, run a simulation with a reduced number of data (9 input data). As the user gets more familiarized with the interface and methodology, one will be able to take advantage of the advanced data input, thus providing more flexibility in the building characterization and its systems. The goal is to facilitate the familiarization of the beginner user with the simulation methodology by means of a simplified level, and then expand the available resources in a more advanced level.

The simulation management module grants the user access to the simulations one has already run, because simulations are stored in the system. In this module, the user has access to buildings whose simulations have not yet been requested, the list of simulations in progress, the results of the simulations and a list of unfinished simulations (due to an error). The user can also use input data from a previous simulation to create input data in a new simulation.

Regarding the server, in addition to the typical infrastructure of a web application, the system manages the EnergyPlus execution queue. Communication between browser and server is carried out via HTTP and HTTPS and the replies coming from the server have been developed to work on the most typical browsers in the market, in compliance with XHTML Strict standard.
b) Input data – Location and weather
The definition of the location where the building is going to be built is necessary for determining several simulation aspects, to mention: annual climate characteristics, latitude, longitude and elevation. For analysis of the energy efficiency level according with the Brazilian standard, the location also defines the Brazilian bioclimatic zone. The user only chooses among the available Brazilian cities.

c) Input data – Building typical use
The building typical use is an input data. By determining the use of the building (hotel, office, hospital etc) a set of default values will be selected for the building simulation. These default values were defined to represent the reality of the Brazilian buildings.

d) Input data – Geometry
Aiming to ease the process of data input, the tool provides pre-defined geometries for the buildings. It is believed that these geometries will allow the simulation of wide range of Brazilian buildings.

All the building floors have the same geometry and are characterized as illustrated in Figure 2: first floor, intermediate floor, and upper floor. The first floor is in contact with the ground.

![Figure 2 - Types of floors](image)

The rectangular geometry (Figure 3.a) corresponds to the most usual geometry and is therefore the tool’s default geometry. In the simplified data input, the user enters the length and width of the floor, the number of floors and the solar orientation. In the advanced data input the user can configure the floor-to-floor height for each type of floor (first, intermediate, upper) and the width of the perimeter zone. The thermal zones in each floor are defined from the creation of the perimeter and central zones. In the rectangular geometry there are four perimeter zones and one central zone.

![Geometry of rectangular building](image)

a. Geometry of rectangular building  
b. Geometry of U-shaped building
The U, T, H and L-shaped (Figure 3.b to 3.e) geometries are available in the advanced data input, and the user enters the widths and lengths that characterize the building, as well as solar orientation and floor-to-floor height.

**e) Input data – Windows and shadowing**

In the simplified version of the input data the user enters the global WWR (Window-to-Wall Ratio), that is a ratio between the sum of the glazed areas in the building’s facade and the sum of the facade’s area. The created model shall have windows in all lateral facades and in all floors with an area that corresponds to the entered value of WWR. In the advanced version, the user can enter the WWR values for each of the building’s facade.

The external window shadowing (fins and overhangs) can be modelled through knowledge of two angles:

- **VSA** – Vertical Shadowing Angle: corresponds to the angle, measured in a vertical plane perpendicular to the window, which is formed between the window plane and a line that passes through the inferior border of the window and the overhang border. An example is illustrated in Figure 4.
- **HSA** – Horizontal Shadowing Angle: corresponds to the angle measured in the horizontal plane perpendicular to the window, which is formed between the window plane and a line that passes through the fin border and the consecutive fin base. An example is illustrated in Figure 5.
In the simplified input data, the shadowing is equally chosen for all windows in the building, whereas in the advance mode the user can enter VSA and HSA for each of the building’s facade.

**f) Input data – Constructive materials**
The tool also provides the main constructive materials used in the construction of commercial buildings in Brazil. The Brazilian standard NBR15220 (ABNT, 2005) was adopted as groundwork for characterizing constructive materials.

The user can select the constructive materials for the outside walls, roof, floors, and windows. In the advanced data input the user can select the constructive component of the skylight opening (if applicable).

In addition to the constructive materials, the user can customize new components by combining registered materials and changing their thickness.

**g) Input data – Internal and external gains**
The internal gains are defined by data input corresponding to the equipment power density (W/m²) and area per occupant number (m²/people). In the simplified data input these values are the same for all the building, whereas in the advanced input such values can be distinct for each of the typical floors. The schedule and the percentage during which the equipment are turned on and people are in the building are pre-defined by a default schedule (defined by the building typical use), with the possibility to configure the schedules in the advanced data input.

External air infiltration to the interior of the building is modeled by defining the number of air exchanges per hour taking place in the building. The value of this variable for each of the typical floors and the schedule can be edited only in the advanced data input mode.

**h) Input data – Lighting**
Lighting is characterized by an input data named lighting power density (W/m²). In the simplified version, this value is the same for all the building, but the users can enter a specific value for each typical floor in the advanced mode. The schedule and percentage during which lighting are turned on is pre-defined by a default schedule (determined by the building typical use), which can be edited in the advanced data input mode.

**i) Input data – Air-conditioning system**
The user has the following options of air-conditioning systems:
• split system using direct-expansion cooling;
• packaged variable air volume system using direct-expansion cooling;
• fan coil system with boiler and air-cooled chiller;
• variable air volume system with boiler and air-cooled chiller;
• fan coil system with boiler and water-cooled chiller;
• variable air volume systems with boiler and water-cooled chiller.

These systems are the same as the EnergyPlus templates. Therefore its modelling has already been implemented. These capacities can be either entered by the user or sized by EnergyPlus.

Regardless of which system the user chooses, it is necessary to define a schedule with setpoint values for heating and cooling. The choice of the air-conditioning type defines the set of input data the user will provide. For example, if the selected system is a split system, then the user must provide the following input data for each typical floor: outdoor air flow rate per person, outdoor air flow rate per floor area, cooling setpoint, heating setpoint, coefficient of performance for cooling and heating.

j) Output data
The S3E tool presents as output the efficiency level according Brazilian Labeling process (label A, B, C, D or E), annual energy consumption of building (kWh/year), annual energy consumption per floor area (kWh/m².year), monthly energy consumption (kWh/month). All consumption are divided into the following parcels: pumps, fans, heating, cooling, lighting and equipments. These results are presented in tables and also in bar and pie graphs.

The Application of S3E Tool in Design Process

The potential use of S3E tool in efficient building design process will be exemplified here with an analysis of energy saving achieved through the use of overhangs on the windows.

The baseline building was defined as office building, rectangular geometry (40x20 m), 3 floors and located in São Paulo, Brazil. The larger facades have WWR = 40 %, while the smaller ones have WWR = 20%. One of the facades with higher amount of windows (WWR = 40%) is directed to the Northeast. The other characteristics of the building (materials, occupation, etc.) were defined as typical of Brazilian commercial buildings. The baseline don't have any sun protection on the windows (HSA=VSA=0). Energy consumption were obtained using the simulation of the baseline and identical buildings which overhangs in the Northeast windows were introduced. The length of the overhang is being gradually increased so that the vertical shading angle (VSA) was increased from 0 ° to 60 ° in 5 ° steps. The graph in Figure 6 illustrates the results obtained for the annual cooling consumption when different sizes of overhang are used (VSA).
The results show that energy consumption is reduced with the increase of the overhangs, but following a parabolic behavior. Energy saving is higher in the first increments become smaller in the next increments. The graph in Figure 7 shows the percentage of energy savings for each increase of 5 ° in the vertical angle of shading (VSA).

The designer of the building could set the size of the overhang checking what is the biggest VSA which provided a certain minimum percentage of energy savings when VSA was increased by 5 °. For example, if the minimum percentage of 1.5% was adopted, the size of the overhang would be one where VSA = 25 °.

Conclusions

The computational tool S3E allows the simulation of commercial buildings by means of a user-friendly interface adapted and designed for the Brazilian reality, thus helping diffuse the use of energy efficiency simulation in Brazil, expand the use of the simulation method in the process of commercial building labeling and foster the construction of energetically efficient buildings.

So far the feedback received by the first users has been positive. The main features praised by users were easy data input, access from any computer, quick results, and easiest way to evaluate the efficiency label according to the Brazilian Building Energy Efficiency Program.

Some materials manufacturers that got to know the tool have shown interest in collaborating with its development. It is believed that the dissemination of the tool in the market will cause a significant increase in data regarding materials and equipment used in the Brazilian market, as manufacturers will provide such data to the S3E tool.

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