Comparative analysis of building performance simulators
Case study: Nearly Zero Energy Buildings

Carlos Miguel de Almeida Rodrigues
miguel.almeida.rodrigues@ist.utl.pt

Instituto Superior Técnico, Lisbon, Portugal
June 2017

Abstract

The construction industry is currently undergoing a process of energy and environment transformation considering the goals proposed by the European Union (EU) for the coming years. The importance of energy efficiency and indoor comfort within the building process enhance the need for usable work tools that can easily support the development of new and more responsible constructive solutions. In this dissertation, the aim is to address the usefulness of building performance simulators for that purpose.

One of the proposals introduced by the EU to reduce the energy consumption of the construction industry is the implementation of nearly zero energy buildings (NZEB), an important concept for the future of architecture that will come into force in 2020. The current progress in Denmark and Portugal and the initiatives in place to fulfill the NZEB goal are compared and discussed in this dissertation. As means of supporting the development of this concept, two building performance simulators frequently used by Denmark and Portugal are tested: BSim and DesignBuilder, respectively. The aim is to make a comparative analysis of both programs through their application on a NZEB housing complex project.

This dissertation intends to address the importance and potential of energy and environmental performance simulators in the construction industry to help architects accomplishing the proposed NZEB challenge.

Keywords: Environmental, Performance, Simulators, Buildings, NZEB

1. Introduction

Architecture in recent years has been relying on new strategies of representation and analysis of buildings, namely the use of building performance simulators (Mills 2004). This modeling process allows us to visualize a wide selection of information regarding the components of the project, such as spatial geometry, materials, and installations. This communication ability improves our understanding of the way buildings work and enables the analysis of thermal, solar, atmospheric, and energetic behavior. The results taken from the simulation anticipate the impact that constructive choices have on the project.

The role building performance simulators can play in the field of architecture is the central theme of the dissertation, in which is proposed a comparative analysis of two simulators applied in a case study.

Objectives

The dissertation aims to expose the potential of building performance simulators given the NZEB target set for 2020. BSim and DesignBuilder will be applied on a NZEB academic project conducted by myself and my working group in Denmark in 2015. This exercise intends to test the following points regarding the case study:

1. The primary energy consumption for heating, cooling, ventilation and domestic hot water (DHW) shall not exceed 20 kWh/m² (limit established by Denmark)

2. The indoor temperature and air quality are within the requirements of the Danish Building Regulations

3. What is the area needed in renewable energy to cover the final energy consumption?

It is intended to ensure that the case study meets the main criteria of the NZEB definition of Denmark.
Methodology

The dissertation is theoretical and practical and is organized according to a comparative study of two different simulators of energy and environmental performance, in this case BSim and DesignBuilder. The content of the work is essentially divided into two parts:

1. State of the art: introduction of the selected programs for analysis and discussion of concepts that are essential for the exercise, which in this case is the NZEB concept as a goal proposed by the European Commission for 2020.


The structure of the dissertation is organized in a progressively specific way, as seen in Figure 1.

Figure 1. Methodology and structure.

The research used to carry out the dissertation focuses on the European directives, publications on NZEBs, support manuals for the simulators and information handled within the scope of the case study itself.

2. State of the art

The road to sustainable development is a reality that has been discussed since the 1980s (World Commission on Environment and Development 1987) and is currently the goal for the future. Concerns about climate change and the pressure on natural resources to respond to the needs of the population require extreme changes in environmental and energy policies for the coming years (European Commission 2010). In 2010, a strategic plan for smart, sustainable, and inclusive growth for the next ten years was issued in the European Union (EU) entitled “Europe 2020”. This plan proposes five measurable objectives for 2020, one of which is aimed at addressing climate change and energy consumption.

Nearly Zero Energy Buildings

Buildings are 40% of total energy consumption in the EU (European Commission 2010). In order to achieve the targets, set for 2020, it is important to rethink how new buildings are built and how we can intervene in existing ones. The Energy Performance Building Directive (EPBD) promotes the improvement of the energy performance of EU buildings, considering the external climatic conditions and local conditions as well as requirements for indoor environment and profitability. The strategy proposed for Member States is to draw up national plans to increase the number of nearly zero energy buildings (NZEB).

NZEB is a concept that has gained international attention in recent years and is now seen as a goal in building design. However, there is no consensus in its definition, because it is open to several interpretations on how to define the concept and what methodology to use to achieve this. From a general point of view, a NZEB is a building with reduced energy needs that are only assured by renewable energy sources (RES). Its practical application is conditioned by the objectives established by the client, by the geographic, economic, and social context of the project and,
mainly, by the definition of parameters of the
calculation methodology.
In this dissertation, two distinct cases are addressed
in the EU, the first being Denmark and the second
Portugal. Both have committed themselves to define
strategies that will contribute in the reduction of
primary energy consumption and GHG emissions,
as well as increasing the use of renewable energy in
the various sectors. It is important to understand
what contributions are being made in developing the
national definition of NZEB and how the architect
can contribute to its practical implementation.

Denmark is one of the Member States which
currently has a structured plan for the construction
of this building from 2020. By definition, a residential
building is classified as Class 2020 if its nominal
primary energy needs per square meter of heated
area for heating, ventilation, cooling and DHW do
not exceed 20 kWh/m² per year. In case of another
type of building, the need for lighting is added and
the total can’t exceed 25 kWh/m² per year (The
Danish Government 2015)

Portugal currently does not have an exact
definition of NZEB, although it has shown efforts to
ensure compliance with the european targets, such
as the Energy Certification System (SCE). The SCE
appears with the objective of improving the energy
and environmental performance of buildings and
encouraging the reduction of the energy needs of
new buildings or subjected to rehabilitation (ADENE
2017). Additionally, the path to the NZEB depends
on the costs associated with its execution, and the
lower the energy consumption of the building and
the greater its profitability, the closer we are to a
cost-optimal point.

Both Denmark and Portugal are actively working
on the targets proposed by the EU for 2020, namely
the NZEB definition. Although some of the essential
aspects of this type of building have already been
studied and defined, the process is always open for
future changes. Decisions may be adjusted if
necessary, even after the deadline. Building
performance simulators are tools that can help us
achieve the NZEB definition, so it is discussed in this
dissertation two examples associated with Denmark
and Portugal, BSim and DesignBuilder respectively.

Building performance simulators: BSim and
DesignBuilder

The programs selected for the comparative
analysis are BSim and DesignBuilder. BSim is a
danish product used in workshops and educational
establishments in Denmark (Simulation & Bsim
2002) and DesignBuilder, although not
manufactured in Portugal, is one of the most widely
used programs at national level, especially for the
purpose of energy certification and supervision of
building regulations (DesignBuilder Software Ltd
2017). The objective of this exercise has two parts,
first it is intended to present two work tools that
contribute to the development of a building project
through energy calculation and environmental
comfort, being two of the essential aspects for the
good performance of the work. Second, it is
important to make the architect aware of the
usefulness of these programs in the NZEB plan for
2020 and in the support they give to the evaluation
of the requirements established by the building
regulations.

BSim is a software developed by the Danish
Building Research Institute (SBI) used to analyze
the internal climatic conditions of buildings and
installations and to calculate their expected energy
consumption. Includes a collection of advanced
tools for simulation and calculation of indoor
temperature, lighting conditions, natural ventilation
and electrical performance of solar panels
integrated in buildings. Through geometric and
mathematical modeling, BSim allows us to simulate
complex constructions with advanced heating and
ventilation systems and operational strategies that
vary throughout the day and year. The program is a
support tool for architects and engineers in the
planning and design of projects, especially in the
comparison and analysis of different proposals in
terms of energy consumption, thermal and air quality
and natural light conditions. It is used to a large
extent by danish engineering firms, engineering
schools, health services and local authorities and is often required to document the environmental conditions of buildings. BSIm has gained international attention because of its advanced simulation capabilities and intuitive user structure, being widely used in Europe and in countries such as Japan, Malaysia and New Zealand (Danish Building Research Institute 2002).

DesignBuilder is a software manufactured by DesignBuilder Software Ltd in the UK that provides a comprehensive environmental performance database for the calculation and analysis of energy requirements and environmental conditions of highly complex constructions. Some of its features include the calculation of energy consumption, thermal simulation of ventilated spaces, forecast of sunlight distribution and design of HVAC systems with detail. The program uses the regulations and database of ASHRAE 90.1 (Energy Standard for Buildings Except Low-Rise Residential Buildings), a US standard that provides the minimum requirements for energy efficiency of systems and buildings, except low residential buildings. DesignBuilder is also used as means of energy certification and verification of compliance with building regulations in several countries, including Portugal. It is, therefore, a reference tool for architects and engineers and a useful tool for communication between different fields of expertise.

Both BSIm and DesignBuilder have very complex and advanced tools that can help us design projects. It is intended for this comparative analysis to be clear and informative on the different aspects present in each simulator and that we can take useful conclusions and suggestions from the process.

3. Case study: NZEB housing complex

The comparative analysis of BSIm with DesignBuilder will be done through the application of the programs on a NZEB housing complex, which was developed under the Sustainable Architecture course of the Integrated Masters in Architecture and Design, University of Aalborg. The exercise proposed the creation of an NZEB housing complex in the center of Aalborg, Denmark, that must meet the Danish criteria set for 2020.

Rules

The main objective is to not have a primary energy consumption of more than 20 kWh/m² per year. With respect to specific rules of the statement, the complex would have to respect the following points.

Regarding the complex:
1. The complex must have at least two physically separated units;
2. The complex must be at least 3 stories high;
3. The building floor area ratio must be between 100% and 200%;
4. 50% of project area is dedicated to family apartments;
5. 20% of total floor area may contain commercial or other public functions.

Regarding the apartments:
1. Family apartments must have an average area of 115 m² per family;
2. Multifamily apartments must include at least three bedrooms and a direct connection to an outdoor area with a minimum of 20 m²;
3. Car parking is distributed as half of a parking lot per family, and there is also space for storage of bicycles.

After meeting the criteria of 20 kWh/m² per year through the spatial and constructive solutions implemented, the complex should reach 0 kWh/m² with the integration of RES. The exercise allowed free choice of active solutions (solar panels, wind turbines, heat pumps).
**Project**

The principle defined for the project is to bring the essence of community gardens to an urban environment. It is intended to merge nature with residential buildings through the integration of public green spaces, gardening and direct contact with natural materials such as wood and stone. The orientation of the housing complex was based on the importance attributed to solar exposure in the apartments. The result consists in the insertion of regular blocks oriented to the south, being that the regularity contrasts with the organic form of the terrain and differs from the urban mesh by its shape and spatial positioning. The area is cut by a new link between the access road to the site and the south of the city, becoming a new route for pedestrians and cyclists.

The housing complex consists of four family blocks and two blocks for students and couples. This differentiation is mainly due to the lifestyle of each age group, with families tending to prefer a stable and private place, while students and couples are more connected to the urban environment and may not stay in the apartment during a long period of time (temporary accommodation). The whole structure is founded on a floor designed for parking and commercial area, with a roof converted into communal gardens for leisure and gardening practice. A new urban park positioned to the south is designed for city use.

Given the inherent complexity of the project, the comparative analysis of the BSim and DesignBuilder simulators is done using only one apartment instead of the entire housing complex. Although the results obtained from the analysis do not represent the energy performance of the whole project, it is possible to arrive at conclusions of the constructive solutions used and if these are suitable for the apartments of the complex taking into account the NZEB definition of Denmark. The apartment selected for the comparative analysis is a T3 typology apartment located on the 3rd floor of a family block.

**Comparative analysis**

The comparative analysis between BSim and DesignBuilder in the apartment is divided essentially into "Model", "Materials" and "Systems". This exercise intends to understand the operation of both programs and how the methodology of each one affects the energetic and environmental behavior of the model.

The first part of the case study analysis focuses on modeling the apartment in both simulators, BSim and DesignBuilder. The modeling process involves understanding the design of the project and reproducing it reliably, taking into account the various external factors. From the model created, it will be possible to add the materiality of the building elements and define the operating systems of the different thermal zones.

The second part of the case study analysis focuses on the materials used for the construction of the NZEB housing complex. The choice of materials...
strongly influences the energy performance of the apartments by their transmission capacity and heat absorption, especially in places with notable differences in exterior and interior temperature. An apartment capable of adequately storing the thermal gains from sun exposure or from the house itself does not need an increased energy consumption to meet the heating needs of the users.

The third part of the case study analysis focuses on the systems. Systems allow to simulate the energy needs throughout the year based on the integrated solutions in the project. During the warm-up months, it is normal to resort to radiators or heat recovery units for thermal gains, just as during the cooling months natural ventilation and shading are performed to cool the interior and renew the air. The mechanisms installed and the way they are controlled need to be defined to simulate the housing conditions and the respective energy consumption. Since we are analysing a NZEB building in Denmark, we need to determine the needs included in the definition, which are:

1. Heating
2. Cooling
3. Mechanical ventilation
4. Domestic hot water

The results obtained in these four systems are those that contribute to the calculation of the primary energy consumption of the apartment. However, the thermal and air quality do not depend exclusively on these systems, since other factors are decisive for a more accurate result of the energy needs. These factors contribute indirectly to the thermal gains and losses of the apartment and should therefore be simulated as well. Additional systems to include are:

1. Natural ventilation
2. Infiltration
3. Equipment
4. People

Both BSim and DesignBuilder enable the user to define the parameters of each of these systems and how they are controlled throughout the year.

Results and discussion

After defining the parameters of "Model", "Materials" and "Systems", the simulation in BSim and DesignBuilder was performed. This simulation reflects the thermal and energy behavior of the apartment during a year, and the results will serve to verify the criteria established by the NZEB definition of Denmark and compare the values given by the programs.

The calculation of the primary energy consumption is done using the results obtained from BSim and DesignBuilder.

Table 1. Registered energy needs.

<table>
<thead>
<tr>
<th>Energy needs</th>
<th>BSim</th>
<th>DesignBuilder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>740.06</td>
<td>791.06</td>
</tr>
<tr>
<td>Cooling</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Mechanical ventilation</td>
<td>273.82</td>
<td>222.58</td>
</tr>
<tr>
<td>DHW</td>
<td>1304</td>
<td>1104</td>
</tr>
</tbody>
</table>

In addition to the energy needs, conversion factors must be considered. The values are determined according to the energy required to produce each energy source. The more renewable the source, the lower the factor.

Table 2. Conversion factors for 2020 in Denmark.

<table>
<thead>
<tr>
<th>Primary energy conversion factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
</tr>
<tr>
<td>District heating</td>
</tr>
<tr>
<td>Gas, oil, wood</td>
</tr>
<tr>
<td>Renewable</td>
</tr>
</tbody>
</table>

In the apartment, heating and domestic hot water needs are covered by the Aalborg district heating, which corresponds to a factor of 0.6. For mechanical ventilation, the fans in the system work by means of electricity, with a factor of 1.8. The apartment is also 88.4 m². This means the primary energy consumption in the two programs is:
BSim: \[
\left( \frac{740.13}{88.4} \times 0.6 \right) + 0 + \left( \frac{273.82}{88.4} \times 1.8 \right) + \left( \frac{1304}{88.4} \times 0.6 \right) = 19.45 \text{ kWh/m}^2
\]

DesignBuilder: \[
\left( \frac{791.06}{88.4} \times 0.6 \right) + 0 + \left( \frac{222.58}{88.4} \times 1.8 \right) + \left( \frac{1104}{88.4} \times 0.6 \right) = 17.40 \text{ kWh/m}^2
\]

According to the results obtained in the equation, both programs confirm the NZEB status of Denmark. In BSim, the starting apartment should not consume more than 19.5 kWh/m² of primary energy in one year, taking into account the various needs in question. Regarding the DesignBuilder model, it needs slightly less energy than the first, approximately 17.4 kWh/m² per year. Therefore, the constructive and spatial solutions implemented in this case ensure low energy needs without compromising thermal comfort and indoor air quality.

In order to reach the zero energy level, the final energy consumption needs to be reduced to 0 kWh/m². This implies the use of active solutions in the housing complex that produce the equivalent of the energy needs of the apartment. For this goal, it were installed photovoltaics capable of generating electricity in a sustainable way. Polycrystalline panels were integrated in the complex, an inexpensive and aesthetically more appealing option than the monocrystalline. The highest efficiency model for polycrystalline is 15% and the system factor is 80%. Radiation corresponds to the angle and orientation of the panels relative to the sun, in which case it is assumed that the panels are placed in the flat roof of the multifamily block. This means that the respective value is 999 (Katic 2007). Therefore, the required area of photovoltaic solar panels is:

\[
A = \frac{26.2 \times 88.4 \times 100}{0.15 \times 0.8 \times 999} = 1932 \text{ m}^2
\]

It is concluded that an investment of 1932 m² of photovoltaics is necessary to ensure the final energy consumption of the apartment.

4. Conclusions

The exercise carried out in the dissertation was to ensure that the annual primary energy consumption of the apartment did not exceed 20 kWh/m² for heating, cooling, mechanical ventilation and DHW. According to the results obtained in BSim and DesignBuilder, this condition is fulfilled in both programs, as well as the analysis of thermal comfort and air quality, which show values within the limits established by Denmark. The application of a NZEB in the comparative analysis of two building performance simulators allowed to exemplify a possible strategy, among several, for the realization of this concept.

The themes discussed in this dissertation seek to encourage architects to approach the building process in a more conscious and sustainable way, since functionality and comfort are essential for the project. The building performance simulators show an increasing weight in the construction sector for their ability to calculate the energy and environmental components of the project immediately. The joint collaboration between these work tools and the architect's design allows a greater control and autonomy in the development of architectural works that respond to the future challenges of the constructive sector, which is why it is essential to educate students and professionals so that there is a greater involvement and better communication between the various fields of study.

References


