Building Energy Performance: Comparison Between EnergyPlus and Other Certified Tools

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Abstract. Currently, the energy consumption study in buildings is critical in fulfilling the EU objectives to achieve carbon neutrality. There are several building energy simulation tools and other spreadsheets available on the market. One of the main software tools, the EnergyPlus software, and two Excel spreadsheets developed in Portugal to assess the thermal loads and annual energy consumption in commercial and service buildings are used and compared in this work. A simple 3D building was modeled using SketchUp2017, and the schedules, materials, and thermal loads were defined for a typical residential and service building to perform this analysis.

Concerning the thermal loads, the simulation of a building without insulation using EnergyPlus showed results for heating and cooling, respectively 10% lower and 6% higher when compared with those predicted by RECS with the transient spreadsheet. Comparing with the simplified spreadsheet for the REH, the discrepancy is more significant. These discrepancies occur because RECS and REH use a simple methodology compared with EnergyPlus. The results for heating and cooling in EnergyPlus when a building has insulation show that the heating and cooling demand is 46% lower and 25% higher compared with the results with RECS, respectively. These results show that insulation reduces the heating demand although it impairs the cooling demand when compared with the building without insulation.

Keywords: Building · Energy performance · Simulation

1 Introduction

According to the European Directive 2018/844, almost 50% of the European Union (EU) final energy consumption is used for heating and cooling, 80% are used in buildings. To meet the energy and climatic objectives proposed by the EU, it is necessary to prioritize energy efficiency and the implementation of renewable energies [1, 2]. All new buildings must be nearly zero-energy buildings (NZEB) from December 31st, 2020 [3]. The need to design buildings with energy balance near zero and improve their thermal performances

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requires suitable energy simulation software to estimate energy consumptions better and optimize the design and operational strategies [4].

Most thermal modeling of buildings' energy consumption in Portugal is made in three ways depending on the type of building and increasing complexity: using spreadsheets with a permanent regime model, using simplified time-dynamic software, or using detailed dynamic simulation programs.

Spreadsheets in a permanent regime model are applied to estimate the heating and cooling needs for a residential building (REH). They are built following the Regulation of Energy Performance for Residential Buildings. This regulation was approved by the Decree-Law nº118/2013, which transposed the Energy Performance of Buildings Directive (EPBD) Nº 2010/31/EU of the European Parliament and the Council to the national legal system, thus establishing minimum requirements for new or subject to interventions buildings, as well as parameters and methodologies to characterize the energy performance, for all residential buildings, as a strategy to improve their thermal behavior. The envelope's thermal and energy requirements are expressed in opaque thermal transmission coefficients, glazed elements, solar factors, and ventilation requirements by imposing a minimum value for the air renovation rate. Also, maximum limits were established for heating and cooling energy needs. The Excel spreadsheet uses an almost stationary method (albeit with a thermal inertia term), which means the heat transmission takes place in a steady state featuring the building as a single zone with constant reference internal temperature. Also, it is a seasonal method, estimating heating needs for the heating season (winter) and cooling needs for the cooling season (summer).

The simplified time-dynamic software is applied to estimate the heating and cooling loads for commercial and service buildings (RECS). This software estimate heating and cooling needs by defining the building as a single zone and calculating energy balances on an hourly basis as described in EN ISO 13790 standard. The estimation of the total energy consumption is made through a simple annual calculation, based on rules and orientations presented in Regulation of Energy Performance in Commercial and Services Buildings approved by the Decree-Law nº118/2013.

In Portugal, several Excel spreadsheets have been developed by two institutes, ITeCons and PTnZEB, to facilitate various methodologies. ITeCons made one Excel spreadsheet for residential buildings and a simplified dynamic software (converted to an Excel spreadsheet) for Commercial and Services Buildings. PTnZEB developed a single spreadsheet that suits both buildings. They allow the automatic fulfillment of all information necessary for the emission of energy building certificates.

The determination of the energy consumption for a multizone building is made by computational simulations using programs accredited by the ASHRAE 140 standard. Many software tools are available, e.g., TRNSYS, TRACE 700, Energy Plus, Design Builder, et cetera [5, 6]. There are limitations or less information regarding the calculation methodologies used and detailed access to results in some situations. Hence, the specific objective is to evaluate the constraints and compare the results with the various software for the same building. The building will be commercial or residential but straightforward enough for easy implementation of different commercial software.

Regarding software tools, De Boeck et al. [6] provided a literature review about improving the energy performance of residential buildings. They highlighted that the

EnergyPlus is one of the most applied tools. In the literature, there are some research works reporting the analysis of the certification process [7], energy performance of buildings based on the national directives [8–11], and the utilization of building energy simulation tools in the analysis of different problems [12–16]. However, it is essential to understand the differences between the Excel spreadsheets developed based on the European Directives and the more sophisticated building energy simulation tools, and up to date, to the authors' knowledge, there is no information about this matter. In this way, this study intends to overcome this need by acquiring more knowledge on building thermal simulation through understanding and comparing the different methodologies used to assess the building thermal energy requirements. Furthermore, the influence of the building thermal insulation on the heat and cooling demands was analyzed.

2 Case Study

2.1 Building Description

The first step for studying thermal behavior and estimating heating and cooling needs is creating the building. The base building, presented in Fig. 1, consists of a rectangular prism, with a floor area of 6 × 10 m^2 and a ceiling height of 3 m. The south-oriented surface includes 12 m^2 of glazed area. Table 2 describes the wall, roof, and floor area of the exterior envelope. For construction solutions used in the building envelope, two cases were considered: case A without thermal insulation and case B with external thermal insulation (EPS) on walls and roof with a thickness of XX mm, both expressed in Table 2 by the U- Factor (global thermal transmission coefficient). The floor was defined as an exterior surface to reduce potential differences between the Excel spreadsheets and the EnergyPlus since they calculate the ground U-factor differently. The ventilation takes place naturally by infiltration with one renovation per hour. No air conditioning has been sized as well as renewable energy systems (Table 1). The walls and roof have light color. The simple glass constitutes the glazed elements without permanent or mobile devices, and they have a solar factor of 0.85, and the glazed fraction is 1.

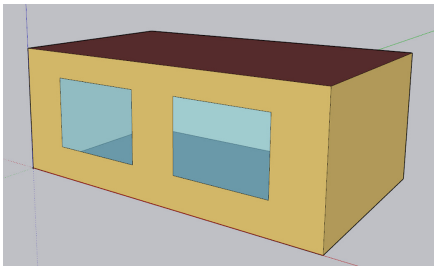

Fig. 1. The geometry of the case study.

Identification of the Climatic Zone. The building's geographic location influences the heat exchanges between the interior of the building and the outside environment due to

Table 1. Material properties of the envelope surface.

	Orientation	Area (m^2)	Case A-U (W/m^2. K)	Case B-U (W/m^2. K)	Solar absorption (-)
Exterior wall	North	30.00	2.00	0,38	0.40
	South	18.00	2.00	0,38	0.40
	East	18.00	2.00	0,38	0.40
	West	18.00	2.00	0,38	0.40
Window 1	South	6.00	6.00	6.00	-
Window 2	South	6.00	6.00	6.00	-
Roof	-	60.00	Upward–1.85 Downward–1.61	Upward-0,32 Downward-0.31	0.40
Floor	-	60.00	Downward–2.06	Downward-2.06	-

factors such as the temperature and humidity of the outside air, altitude, and prevailing winds at the location [17]. The building was assumed to be located in Viana do Castelo County at an altitude of 268 m at a distance from the coast greater than 5 km.

CLIMA-SCE software version 1.05 was used to create the climate file that will later be used in the simplified and detailed dynamic simulations. The climate file used in simplified dynamic simulation has the following extension ".dat" while in EnergyPlus, it has "epw". Both climate data are written on an hourly basis and represent a Typical Meteorological Year (TMY) (Fig. 2).

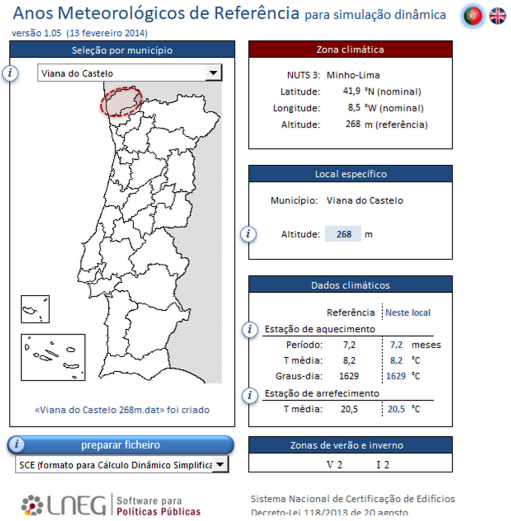

Fig. 2. Weather file: CLIMA-SCE 1.05.

Utilization Profile. In residential buildings, internal gains are considered constant for all seasons [18]. However, in the spreadsheet for simplified dynamic simulation and energy plus, internal gains vary according to the utilization profile. Internal gains are divided into internal gains by occupants, lighting, and electric equipment. For each one, three utilization profiles must be defined that depended on room type. In this study, it was defined as office space with a maximum of four persons (Fig. 3).

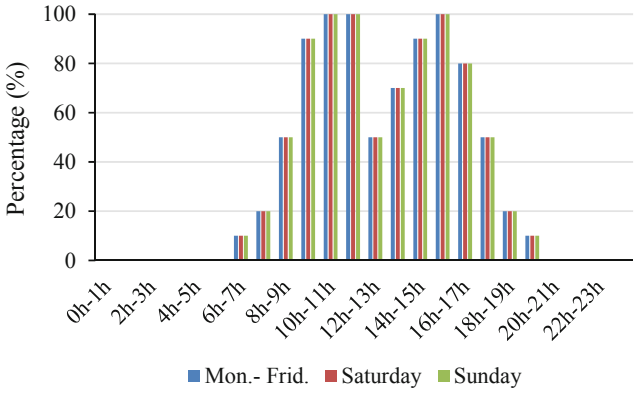

Fig. 3. Weekly occupation profile.

Thermal Loads. In residential buildings, internal heat gains assume a constant value of 4 W/m^{2}[18].still, in commercial and service buildings, they are different for each parcel and depend on the number of persons and their activity, expressed as metabolism rate. The illumination and electric equipment load depend on space type. For that case, regulation of energy performance in commercial and services buildings presented, according to space type, reference values for illumination and electric equipment. Present the occupation, illumination, and electric equipment loads used for simulations.

Table 2. Parameters defined to characterize the occupation inside the building.

Activity	Metabolism	Occupants	Thermal load (W)	Total sensible load (W)	Total latent load (W)
Sedentary	69.78	4	505.20	282.32	222.89

Table 3. Parameters defined to create the illumination and electric equipment profiles.

	Thermal load (W)	Released thermal load(%)
Space (office)	720	100
Equipment (default)	300	100

2.2 Building Energy Simulation Tools

Spreadsheet for Residential Buildings (REH)–Seasonal Method. With climate data and the characteristics of the buildings, now is it possible to estimate the heating and cooling needs for different simulation tools for residential buildings. It uses a spreadsheet in a permanent regime, which uses a seasonal method, assessing heating needs for the heating season (winter) and cooling needs for the cooling season (summer). From climate data, heating degree days and the heating season duration as well medium solar energy received in a south vertical envelope, is necessary for calculating heating energy needs, while the medium exterior temperature and the solar energy accumulated during the cooling season received on horizontal and vertical surfaces [18].

The value of the annual nominal needs of useful heating energy in heating season for building, N_{ic}, is calculated by the following expression [19]:

$$N_{ic} = \left(Q_{tr,i} + Q_{ve,i} - Q_{gu,i}\right)/A_p \tag{1}$$

where $Q_{tr,i}$, $Q_{ve,i}$, and $Q_{gu,i}$ are the transmission heat transfer through the building envelope and by ventilation and thermal increase from internal gains plus solar gains, respectively (kWh). A_p is the useful interior area of the building (m^2).

The value of the annual nominal needs of cooling useful energy in heating season for building, N_{vc}, is calculated by the following expression [19]:

$$N_{vc} = (1 - \eta_v)Q_{g,v}/A_p \tag{2}$$

where η_v is the utilization factor in cooling station, $Q_{g,v,}$ gross thermal gains in cooling season (kWh) A_p is the useful interior area of the building (m^2).

The utilization factor is the function of transmission heat transfer through cooling season and air renovation and thermal gains in the cooling season.

Spreadsheet for Commerce and Services Buildings (RECS)–Simplified Dynamic Simulation. The heating and cooling demand estimation is done through an energy balance on an hourly basis according to the norm EN ISO 13790:2008. This method approximates a zone thermal to an electrical circuit establishing equivalences between electrical current and heat flows and represents in the form of an electrical scheme consisting of 5 resistors and 1 capacitance. The values of each temperature node are determined using the Crank-Nicholson iterative method, allowing the heating and cooling energy to be calculated every hour and per unit area of the thermal zone [20]. For calculation of heating and cooling energy needs is essential to choose the set-points temperature. In this case, the minimum setpoint temperature is equal to 20 °C, and the maximum temperature is 25 °C. If air indoor temperature is less than minimum setpoint

temperature, then heating need is required. If air indoor temperature is higher than maximum setpoint temperature, the cooling demand is required. All equations and procedures are described in EN ISO 13790:2008 [20].

The spreadsheet given by PTnZeb and ITeCons brings a calculation motor integrated that quickly calculates the energy needs. All it needs is the climate file, created in CLIMASCE 1.05 software, and the introduction of all building characteristics in the spreadsheet and then run the simulation.

EnergyPlus-Detailed Dynamic Simulation. The EnergyPlus program is a collection of many program modules that work together to calculate the energy required for heating and cooling a building using various systems and energy sources. This tool was approved by ASHRAE 2004 standard, and it is based on two tools developed during the 70s after the oil crisis: BLAST and DOE-2 [21]. The software can model with excellent precision radiant and convection heat fluxes between indoor and outdoor, HVAC systems performance, heat exchanges with the ground, thermal comfort, natural, artificial, and hybrid systems. Additionally, it can simulate ventilation and airflows and allow dynamic transient simulations with a time interval between 1 h and 1 min, using an hourly representative year [21]. The simulation process started with defining the points presented in the previous subsection (Geometry, Weather zone, Schedules, Materials, Thermal loads, and setpoint temperature) [22]. After this process, the simulations are performed to obtain the heating and cooling demands. The simulation is based on the solution of the heat balance equation through the surfaces of the building [23]. It is essential to point out that the 3D model was made in SketchUp2017 and associated with the plugin OpenStudio. All building's surfaces were defined as well as their boundaries conditions. Compared with other simulations done before, it is used in the same building with the same characteristics. All building envelopes have outdoor conditions, and it was defined in only one thermal zone. After defining the 3D Model, the model was extracted to the OpenStudio plugin connected to the EnergyPlus.

3 Results and Discussion

In this section, the simulation results for the building with insulation are presented and discussed. Figure 4 shows the air temperature variation inside the building for a winter day and a summer day in RECS (simplified dynamic spreadsheet) and EnergyPlus. These days were selected because they are the warmer and cooler days of the year.

With the EnergyPlus software, air temperature reaches setpoint temperature earlier in the winter day since the setpoint should be obtained at the open time. Then, it decreases before the building closes at 20h00. On a summer day, the results are very similar.

The results of the heating and cooling demands for a building with insulation are presented in Fig. 5. It is possible to observe that EnergyPlus spend more heating and cooling time than RECS on winter and summer days.

This fact can be explained by the different methodologies used to compute the thermal losses by the building surface. With EnergyPlus, the calculation method is more detailed, and more accurate results are obtained. While in RECS, the exterior outside resistance

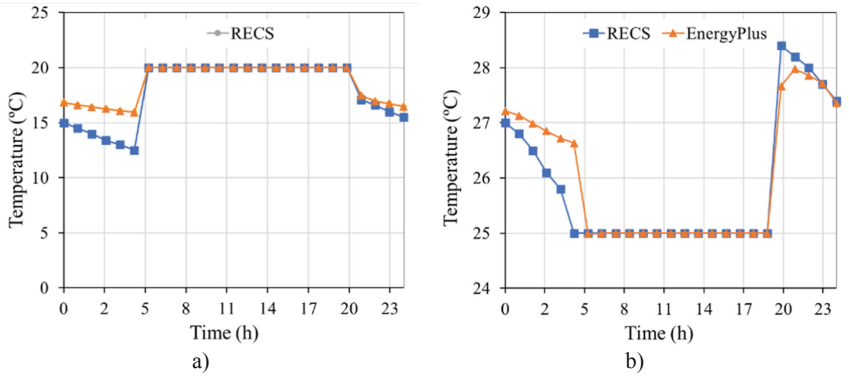

Fig. 4. Variation of the air temperature inside the building with insulation: a) winter and b) summer day.

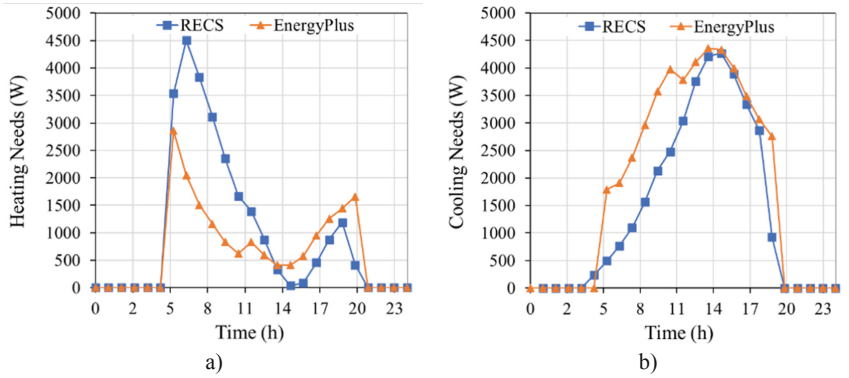

Fig. 5. Variation of the building with insulation energy demand: a) heating and b) cooling in two specific days of winter and summer season.

is constant, EnergyPlus has a comprehensive model for exterior convection by blending correlations from ASHRAE.

Furthermore, the methodology to compute the thermal inertial is different. These facts are the reasons why the results are significantly different. However, if the annual results are compared, the heating demand obtained with RECS is higher than EnergyPlus but lower in the cooling season. Regarding the REH methodology, lower results were obtained due to the simplification of the calculation of this tool where the heating and cooling demands are only computed for the summer and winter months while, with EnergyPlus and RECS tools, the heating and cooling demands are computed for all days of the year that are above or below the setpoint temperature.

Figures 6 and 7 present the air temperature and heating and cooling demand variation in the extreme conditions of the winter and summer seasons for a building without isolation. The tendency of the results is the same but, however, in the summer season, the results are not too different. Regarding the annual heating and cooling demand, the

Table 4. Comparison of the building annual heating and cooling demands between the different software tools (building with insulation).

	EnergyPlus	RECS	REH
Heating demand (kWh)	744	1,391	1,084
Cooling demand (kWh)	5,450	4,037	1,996

difference between the two tools is the same as the previous case. Since there is no insulation, the energy required in the different seasons is higher (see Table 4) (Table 5).

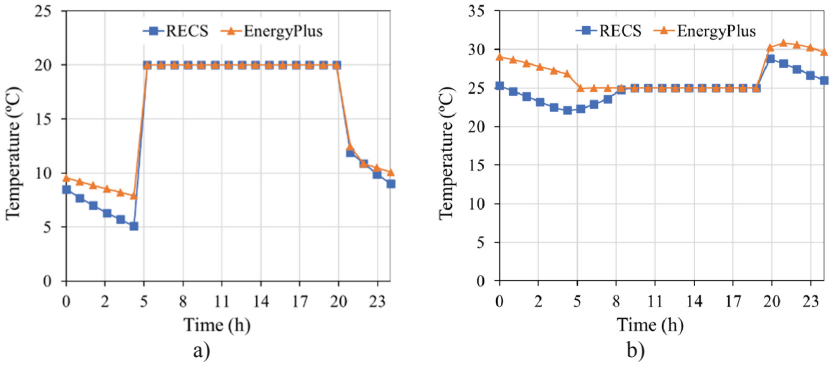

Fig. 6. Variation of the air temperature inside the building without insulation: a) winter and b) summer day.

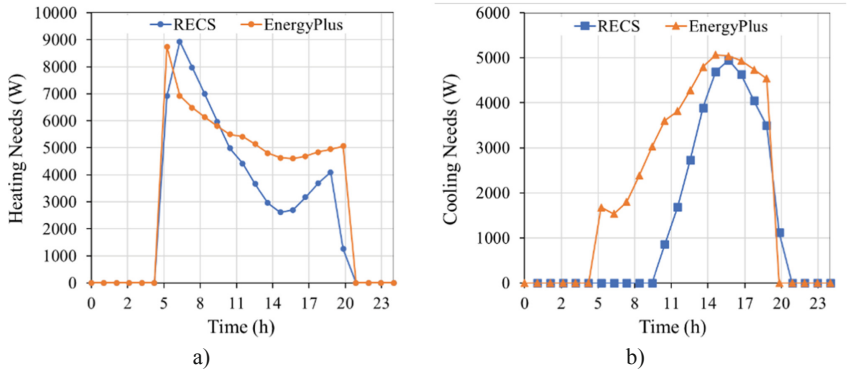

Fig. 7. Variation of the building without insulation energy demand: a) heating and b) cooling in two specific days of winter and summer season.

Table 5. Comparison of the building annual heating and cooling demands between the different software tools (building without insulation).

	EnergyPlus	RECS	REH
Heating demand (kWh)	7,750	8,580	16,494
Cooling demand (kWh)	2,639	2,481	947

4 Conclusions

There are several building energy simulation tools and other spreadsheets available on the market. One of the main software tools, the EnergyPlus software, and two Excel spreadsheets developed in Portugal to assess the thermal loads and annual energy consumption in commercial and service buildings are used and compared in this work. To perform this analysis, a simples building was modeled using Sketchup.

Concerning the thermal loads, the simulation of a building without insulation using EnergyPlus showed that heating and cooling results are 10% higher and 6% lower when compared with the values predicted by RECS. Comparing with REH, the discrepancy is more significant. This discrepancy is because RECS and REH use a simple methodology compared with Energy Plus.

The results for heating and cooling in EnergyPlus when a building has insulation show that the heating and cooling demand is lower 46% and higher 25% compared with the results from RECS, respectively. The results show that insulation reduces the heating demand but, on another side, impairs the cooling demand when compared to the building without insulation. So, it is essential to choose well the type and thickness of insulation. Another reason for high cooling demand is duo to the large size of windows are big and the non-existence of shading devices.

Despite the significant results, the model needs some improvements concerning the complexity of the building, including heating and ventilation systems and different renewable energy sources to meet the energy needs. The integration of all these aspects makes the model more realistic in determining the effective heating and cooling needs.

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