# Energy Performance of a Service Building: Comparison Between EnergyPlus and TRACE700

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**Abstract.** The amount of energy consumed by a building can be estimated by performing dynamic simulations. In this study, two building simulation energy software, EnergyPlus, and TRACE700 were used to assess the energy performance of an existing service building. The building, placed in a specific zone of Portugal, has thirty people and a floor area of 2,000 $m^2$. It consumes mainly electricity, natural gas, and solar energy. The dynamic simulation started with the weather file upload, and then the construction, illumination, interior equipment, and HVAC systems were defined. The results were compared with the actual energy consumption values, and the deviation was 2% in the case of EnergyPlus and 0.5% in the case of TRACE700.

**Keywords:** Energy performance · Services building · Simulation

## 1 Introduction

Nowadays, the energy analysis market is huge due to the European Union (EU) legislation to improve energy efficiency. The energy efficiency in buildings will be, for sure, a significant step forward in the next few years. Estimating the energy consumption in existing buildings will be part of the process [1].

The future EU plans predict that the existing buildings must be transformed into nearly zero-energy buildings. In other words, the EU, with the directives implemented, intend to turn these buildings into energy efficient infrastructures that consume a reduced amount of energy [2].

The application of accurate simulation methods [3] will be crucial in achieving highly energy-efficient buildings and the EU goals. The dynamic simulation of buildings consists of predictions based on computer programs of the amount of energy that a building consumes during a period [4]. Computer simulation software allows the analysis of the energy efficiency of buildings and the estimation of energy consumption necessary to provide the comfort needs of its occupants [5]. Usually, all the available tools work by the same principles and require the same information sequentially. Firstly, the user inserts

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the structural construction parameters, which allows the software to calculate the thermal transmittance coefficient, obtaining, this way, the heating flow exchanged between the inside and outside of the building [6]. Once this flow is calculated, the programs calculate the amount of energy consumed to maintain a comfortable temperature inside of the building [7–10]. In this way, the software computes the energy consumption by all active systems [8–14]. In order to perform the calculations, the user must provide specific data such as the climatic file that contains information about the air temperature, humidity, radiation of the region, construction, occupation, illumination, equipment, and HVAC (Heat Ventilation and Air Conditioning) systems [10, 11]. Then, the software will use a simulation management tool that works as an interface of data exchange, aggregating two modules responsible for the simulation: the heat and mass balance simulation module and the building's system simulation module [15]. The first one performs the thermal balance simulation based on the phenomenon of heat transfer. The second one is responsible for the building's systems simulation; in other words, it does the simulation of HVAC and DHW (Domestic Hot Water) systems. Finally, the output data are analyzed [12, 13]. This process plays an essential role in determining the optimal design variables since the building's response is highly sensitive to the input data provided for the computer simulations. In the building energy sector, whole-building energy simulation programs that mainly consider key performance indicators such as energy demand and costs are the significant tools [17]. De Boeck et al. [18] provided a literature review on improving the energy performance of residential buildings. The author identified the most widely used tools in the literature, and EnergyPlus is one of them. More recently, Hashempour et al. [19] presented a complete, precise, up-to-date literature review on energy performance optimization of existing buildings. The author analyzed the different existing building simulation energy tools such as DOE-2, EnergyPlus, TRNSYS, eQUEST, and IDA ICE. EnergyPlus is the software that presents the highest percentage of the use amongst the different energy dynamic simulation tools and building modeling and/or visualization platforms, respectively. Crawley reported the same conclusion et al. [20] and Sousa [21]. The former compared the top20 simulation tools for building energy performance simulation. The last author reviewed five different simulation tools and concluded that although TRNSYS is the most complete tool, EnergyPlus, and IDA ICE are more adequate to import or export files from AutoCAD Software tools.

There are some research papers in the literature using building energy simulation tools for the analysis of different problems. Shrivastava et al. [22] presented a comparative study of popular simulation tools and their architecture from the perspective of TRNSYS. The author found that this software provided a good agreement within error between 5 and 10%. Furthermore, the author recommended the simultaneous analysis of the same system on different programs to avoid bias results. Sadeghifam et al. [23] examined the energy saving in building elements and how its coupling with effective air quality factors can contribute towards an ultimate energy efficient design. These works were based on a typical house in Malaysia, and the building was modeled using Revit software and then imported to EnergyPlus software to evaluate the best option in terms of energy savings.

Overall, despite different building energy simulation tools, choosing the appropriate tool depends on the final user's objective and perspective. In this way, this paper aims to study the energy performance in an existing building in Portugal and perform the

same analysis using two different programs to avoid biased results as suggested by Srivastava et al. [22]. This is an important work to provide answers to particular questions regarding the energy performance of an existing building. Further, the influence of some key variables can be analyzed quickly and effectively. This is an added value since the owners of the service building will see the building energy demand and what are its cost and energy performance rating.

## 2 Case Study

This chapter describes the building selected as a test case, its location, construction characteristics, occupation, illumination, equipment, and HVAC systems. Then, the energy modeling methodology used in EnergyPlus and TRACE700 is presented, highlighting, and explaining the details of the two models.

### 2.1 Building Description

The building is a nursing home for seniors located in Penafiel, Oporto district, Portugal. The building, made up of floors, is an old construction, which was never retrofitted with any improvement. The first floor, referred to as Floor -1, includes bedrooms, bathrooms, corridors, kitchen, canteen, church, fridge room, and laundry.

The second floor, referred to as Floor 0, comprises bedrooms, a corridor, bathroom, waiting room, and an administrative office. The third floor, Floor 1, also includes bedrooms, hall, bathroom, meeting room, gym, and infirmary.

Each floor has an average height of 3 m. Regarding the building's orientation, the main facade is oriented to the southeast, as shown in Fig. 1. The arrow points to the north.

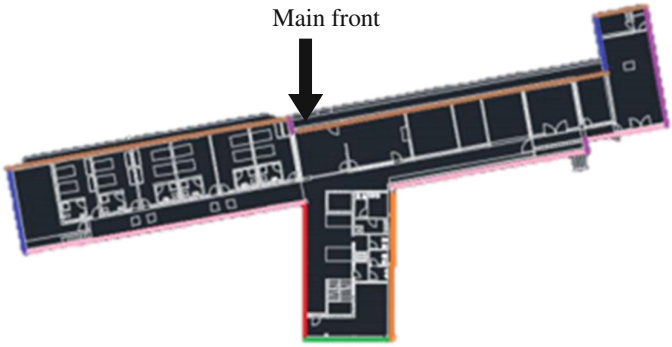


**Fig. 1.** Illustration of the building orientation plan.

**HVAC and DHW Systems.** The building has only one heating system and no cooling systems. It consists of one natural gas boiler that heats the water up to 70 °C. Two electrical pumps pump the hot water to the radiators and fan coils. As far as the domestic hot water system is concerned, this consists of one boiler (the same as the heating

system) that heats the water up to 50 °C, subsequently pumped by two electrical pumps to 2 storage tanks, with a capacity is 300 L each. Besides, there is a supplementary system to the boiler system previously described, consisting of 14 solar collectors that heat water at 50 °C, subsequently pumped by one electrical pump to a 600 L storage (Table 1).

**Table 1.** Characteristics of the building's HVAC and DHW system.

| Equipment | Power (kW) |
|---|---|
| Boiler | 203.6 |
| Pump HVAC | 0.33 |
| Pump HVAC | 0.65 |
| Pump DHW | 0.093 |
| Pump DHW | 0.093 |
| Pump DHW | 0.165 |

### 2.2 Software Implementation

EnergyPlus and TRACE700 are energy simulation software that allows the user to simulate the building energy consumption under different thermomechanical conditions. By introducing the constructive building characteristics, they can calculate the building thermal transmission coefficient and, in this way, calculate the heat losses and gains of the building with the environment. Knowing the occupation thermal comfort needs and the thermal load, the software calculates the energy required for operation.

There are a few differences between these two tools. EnergyPlus allows the user to know the thermal load generated by illumination, occupation, and equipment in non-thermal zones. On the other hand, TRACE700 does not calculate the solar contribution on domestic hot water simulation and does not allow a 3D modeling of the buildings.

The next subsections will present the construction of each energy model on this different software.

**3D Model.** In the EnergyPlus software, the 3D building modeling was developed with the Sketchup graphical interface. Sketchup has an OpenStudio Plug-in, which allows the user to draw the building and, at the same time, to build the energy model. OpenStudio is a data insertion interface that enables the data to insertion to construct the energy model.

The 3D drawing on Sketchup started with the design of the floor, followed by the spaces boundary conditions, the existing solar collectors, and, finally, the building orientation was defined. Figure 2 a) shows the final building 3D modeling, where the cover is brown, the external walls are yellow, and the windows are represented in blue. Figure 2 b) shows the compartment's boundary conditions, wherein green represents the inner walls and floors, grey is used for the floor adjacent to the ground, and blue is for the outer walls and roof.

The TRACE700 software does not allow direct 3D modeling.

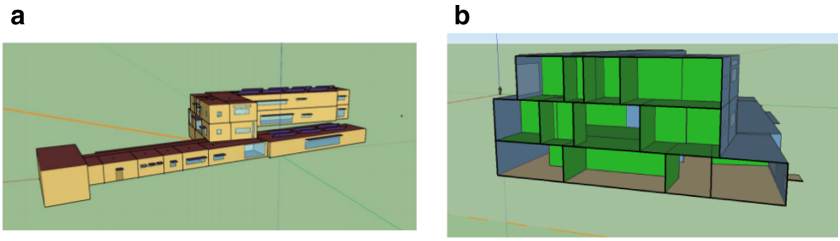


**Fig. 2.** 3D external view of the building: a) EnergyPlus final model and b) compartments boundary conditions. (Color figure online)

**Input Data.** *Climatic Zone.* In terms of data insertion, the climatic file is the first step of data insertion into the software when the user wants to build energy models. In the EnergyPlus, the climatic file upload is carried out on OpenStudio, which is the EnergyPlus input data interface. In the TRACE700, the upload is made directly on TRACE700. In these two tools, the climatic file insertion is very similar.

Firstly, the climatic EPW file is downloaded from an app called CLIMAS-SCE. This app allows the user to obtain the EPW file by inserting the city, its region, and its altitude. From the EnergyPlus website, it is downloaded the DDY. In the specific case of the DDY file, the Oporto DDY was selected as the nearest location to the actual site because it is the only city from the north of Portugal that had a DDY file.

The main difference between the EPW and DDY files is that the first contains information concerning the outer temperature, relative humidity, solar radiation, opaque cloudiness. This information is used by the software to simulate the building's thermal behavior for 8670 h, but this file does not possess any information about the critical days of the year in terms of external air temperature. For this reason, the software needs the DDY file, which provides this information. Figure 3 shows the EPW file down-load on CLIMAS-SCE.

*Thermal Zones.* In this subchapter, the variables that characterize the use of the different thermal zones were defined: the occupation, its metabolic rate, the use of equipment, and lighting. In both softwares, the definition of these variables is very similar. It starts with the introduction of the values related to occupation, lighting, and equipment. This introduction is made for every thermal zone, but in the case of EnergyPlus, it is possible to introduce the values of these variables in non-thermal zones. This introduction is followed by the definition of the lighting, occupation, and electrical equipment working schedules. The service building management provided these data.

*Construction Details.* In both tools, the materials present in the construction were created because these software are much more adapted to the American specifics than European. For the EnergyPlus, firstly, the material layers were formed. In this stage, the variables required for each material from EnergyPlus are the thickness of each material layer, its conductivity, and its thermal resistance. Then the layers are grouped into walls, here identified as the external walls, floors, cover, internal walls, etc. Finally, on the Sketchup platform, using the OpenStudio Plug-in, these constructions were associated with the 3D model, previously created.

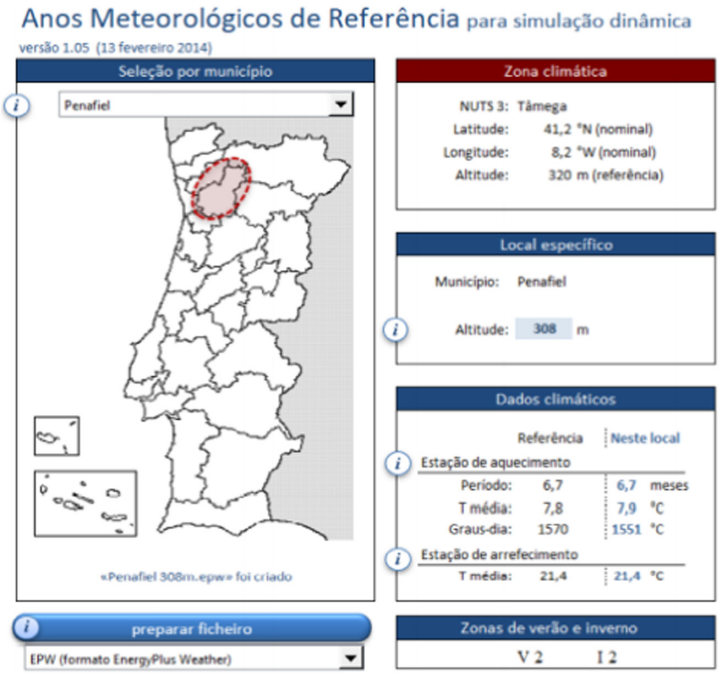


**Fig. 3.** Climas-SCE Software.

On Trace700, the creation of the material layers is not needed. The wall creation is immediately done, and only its thermal transmittance coefficient and its area is required from the software to create the walls. Then the constructions were associated with each thermal zone. Figure 4 shows the construction definition on TRACE700.

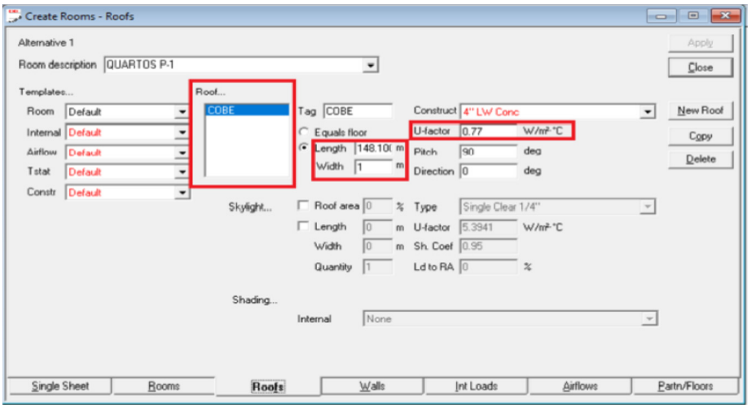


**Fig. 4.** Construction definition on TRACE700.

*Loads.* The loads correspond to the internal gains existing in the thermal zones of the building. These gains are associated with the number of occupants, their expected activity, the power of the equipment, and lighting. The selected building possesses both natural gas and electric powered devices. In both tools, the definition of these variables that contribute to the internal gains is identical. This definition is made for every thermal zone. Table 2 shows the load definition in the energy simulation software.

*HVAC and DHW Systems.* Regarding the HVAC and DHW definition, this task is quite different in both software. On EnergyPlus, this definition starts with the building of an HVAC circuit. Here, firstly, the boiler is added to the circuit, then a pump (the HVAC circuit possesses 2 pumps, but on EnergyPlus has selected only an equivalent pump that corresponds to these two pumps), and finally the radiators and fan coils. When the pump is selected, the option "Auto sized" concerning the pumped water flow and the electric power of the pump must be determined. In this way, the EnergyPlus will calculate the electric power and water flow needed to satisfy the building heating needs. The definition

**Table 2.** Loads defined in the energy simulation software.

| Zone | Number of persons | Light (W) | Electric equipment (W) | Natural gas equipment (W) |
|---|---|---|---|---|
| Bathroom | 0 | 406 | – | – |
| Hall | 6 | 545 | – | – |
| Bedrooms | 12 | 774 | – | – |
| Canteen | 20 | 384 | – | – |
| Kitchen | 4 | 144 | 3,600 | 43,000 |
| Fridge room | 0 | 72 | 37,200 | 21,000 |
| Laundry | 2 | 72 | 1,470 | – |
| Church | 8 | 406 | – | – |
| Hall | 0 | 168 | – | – |
| Secretary | 2 | 108 | – | – |
| Manager's office | 1 | 72 | – | – |
| Waiting room | 2 | 60 | – | – |
| Bathroom (Floor 0) | 0 | 46 | – | – |
| Hall (Floor 0) | 0 | 112 | – | – |
| Bedrooms (Floor 0) | 9 | 1,129 | – | – |
| Hall (Floor 1) | 0 | 316 | – | – |
| Nursery | 2 | 60 | – | – |
| Gym | 3 | 108 | – | – |
| Meeting room | 4 | 60 | – | – |
| Doctor's office | 2 | 78 | – | – |
| Bedrooms (Floor 1) | 9 | 1,129 | – | – |
| Bathroom (Floor 1) | 0 | 23 | – | – |

of an HVAC system on TRACE700 is similar to the EnergyPlus, but here all the HVAC equipment is defined and its characteristics. In the end, the setup temperatures for each month are defined too in each software.

Regarding the DHW system definition, on EnergyPlus is quite similar to the HVAC system definition. Here the circuit is created and then added all the equivalent collectors, pumps, storages (taken as an equivalent of all collectors, pumps, and storages). TRACE700 does not simulate the solar contribution on the DHW system. Having the system of solar collectors, a great contribution to the DHW system, another software (SCE.ER) was used to simulate the DHW system instead of TRACE700. The results of SCE.ER was added to the TRACE700 results.

## 3 Results and Discussion

In this section, the simulation results on EnergyPlus and TRACE700 are presented, discussed, and compared also with real energy consumption results. Regarding the results of the simulations on both software, the EnergyPlus presented a total energy consumption in a year of 1,435.84 GJ and TRACE700, 1,457.72 GJ. The deviation to the real consumption values is respectively 2 and 0.5% for these softwares. The results of both tools were very identical which shows that either software can be used to simulate this type of buildings.

An analysis was made to compare both energy models in terms of natural gas and electricity consumption in the building. Figure 5 shows the monthly variation of the natural gas consumption in both models and the real natural gas consumption. Figure 6 shows the consumption of electricity in each month, comparing both models and the real values recorded.

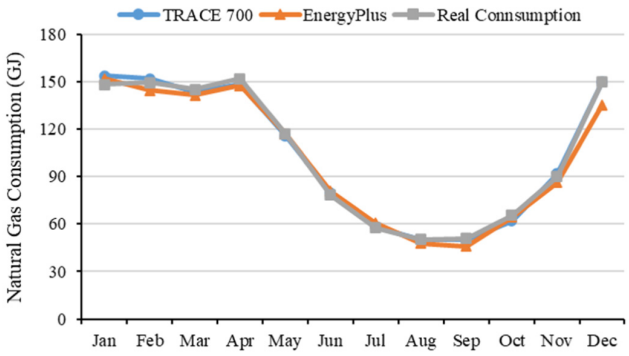


**Fig. 5.** Comparison of natural gas consumption in each month for TRACE700 and EnergyPlus.

The analysis of Fig. 5 shows that either simulation provided identical values, which demonstrates that the use of each tool is reliable. Looking at the values and the curve's path, it is perceptive that the natural gas consumption is higher during the months when the heating needs are higher, so then the boiler has a far higher load during these months.

Observing the data in Fig. 6, the results of each software in terms of electricity consumption are also very similar.

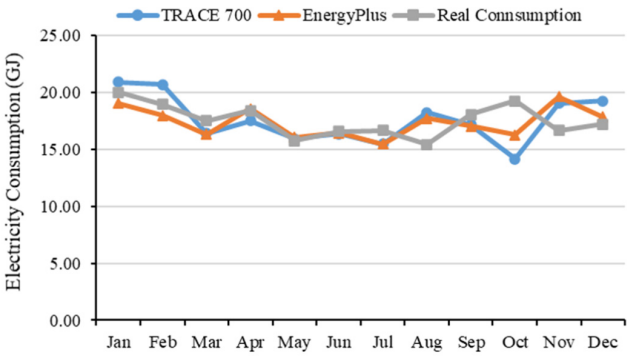


**Fig. 6.** Comparison of electricity consumption in each month between TRACE700 and EnergyPlus.

The differences observed are explained by the "Auto-sized" option for the pump's power, on EnergyPlus. During the heating months, TRACE700 electricity consumption results are higher than with the EnergyPlus. During these months, the pumps present on the TRACE700 model have higher power than those present on the EnergyPlus model.

When the heating system is not working at its highest power, the electricity consumption on EnergyPlus is higher or equal to those with the TRACE700 because the TRACE700 model did not simulate the DHW system.

Figure 7 shows the results of the natural gas consumption and compares these in both models. Analyzing this figure indicates that the kitchen and laundry equipment consumption is constant during the year in both models.

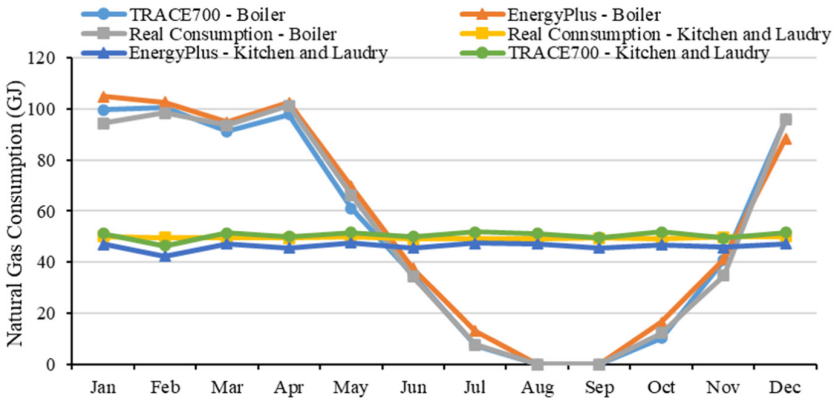


**Fig. 7.** Results of the natural gas consumption in EnergyPlus and TRACE700 for different components.

Figures 8 and 9 show the results of electricity consumption, respectively, in EnergyPlus and TRACE700. In both models, analyzing these two graphics shows that the interior equipment is the major source of electricity consumption. The Fan coils and illumination consumption is constant all the year, and the pumps consume low power during the months when the heating system is off. In the TRACE700 this consumption

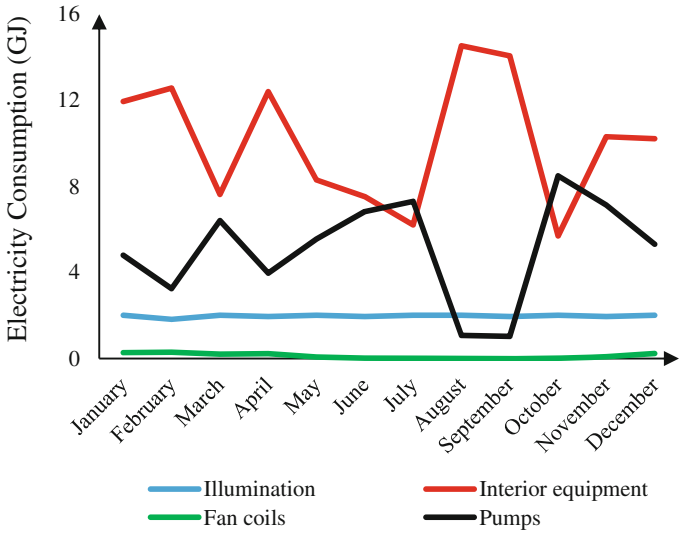


**Fig. 8.** Results of electricity consumption on EnergyPlus.

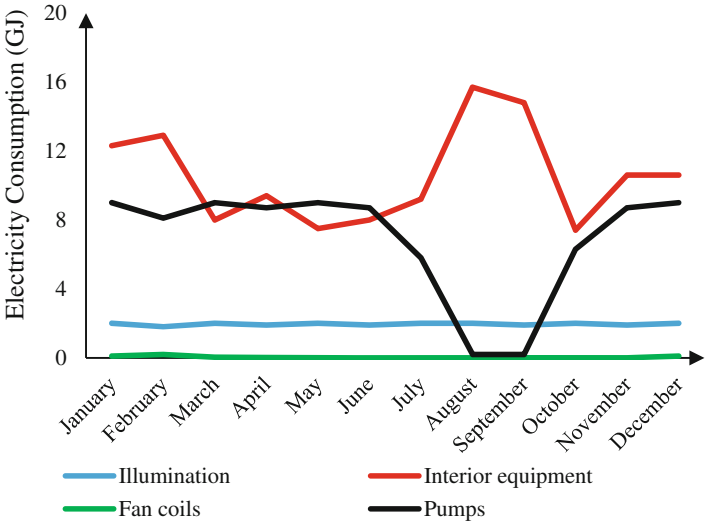


**Fig. 9.** Results of electricity consumption on TRACE700 for different equipment.

is zero in August and September because the heating system is off and, in this model, the DHW system was not simulated.

## 4 Conclusions

After analyzing the results, it is concluded that each software has similar results when simulating the energy consumption in this kind of buildings. The EnergyPlus and TRACE700 models obtained, respectively, 1,435.84 GJ and 1,457.72 GJ. Compared with the real energy consumption values, TRACE700 and EnergyPlus models results had a deviation of 0.5% and 2%, which supports the conclusion of being reliable and suitable to reality.

However, the most significant differences during the model construction are related to the 3D modeling, the use of different interfaces in EnergyPlus, the simulation of the DHW system.

Regarding the negative aspects of these tools, they are much more adapted to the American market than to the European. It can be observed in the libraries where most of the materials and equipment needed are not available. Another negative aspect is the fact that these tools do not calculate thermal bridges.

In conclusion, a brief overview is that both software is a great tool to predict the energy consumption of a services building.

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