

Energy Simulation Software for Buildings: Review and Comparison

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Abstract. Energy simulation software tools are an important support used for building designers to reduce the cost of energy in buildings. The energy simulation software allow to determinate with accuracy some variables that can support designers to take decisions about the best measures to apply for any building to built or already existent. There are several energy simulation software tools in the market. The present study aims to identify some of the most important due to their capacity of calculating a significant number of variables and to compare them in order to establish their differences.

Keywords. Simulation Software Tools, Energy Consumption, Buildings.

1 The Energy Simulation Software Tools

1.1 Introduction

The energy simulation software tools can be important for reducing the cost of energy in buildings [1]. About one third of the energy consumption in buildings is used to increase thermal conditions of the dwellings and for lighting. Thermal simulation software tools for buildings allow to:

- Determine the appropriate size of HVAC systems;
- Analyze the energy consumption;
- Calculate the cost of the energy used.

1.2 Advantages of Energy Simulation Software tools

The rules concerning the requirements on building envelope's thermal behavior have become increasingly restrictive. For instance, in Portugal there are three regulations which requirements should be meet by designers regarding thermal comfort, namely, the RCCTE (Regulamento das Características Térmicas dos Edifícios - Regulation of Thermal Performance Characteristics of Buildings) [2], the RSECE (Regulamento dos Sistemas Energéticos e de Climatização nos Edifícios - Regulation of Energy Systems and Climate in Buildings) [3] and the SCE (Sistema Nacional de Certificação Ener-

gética e da Qualidade do Ar Interior nos Edifícios – National Energy Certification System and Indoor Air Quality in Buildings) [4].

Nowadays, designers need tools that answer to very specific questions even during the initial design phase. Through the use of energy simulation software designers can consider specific choices, (e.g., heating and cooling). Designers can also predict the thermal behavior of buildings prior to their construction and simulate the costs of energy in existent buildings in their current conditions, establishing the best thermal retrofitting measures to adopt in the buildings under analysis. Besides the energy consumption, simulation software tools can also be used calculate to the following variables:

- Indoor temperatures;
- Needs for heating and cooling;
- Consumption needs of HVAC systems;
- Natural lighting needs of the occupants;
- Interior comfort of the inhabitants;
- Levels of ventilation.

The calculation of energy consumptions spent in dwellings still to build or to retrofit allow a more accurate determination of design charges and help to decide with highest accuracy the possible devices to be used in a room (limited zone) or dwelling.

Energy simulation software tools can also allow considering all the regulations in force and simultaneously provide a sense of comfort to its inhabitants through a correct design of heating and cooling systems. Such software have also available tools to improve constructive solutions through simulating the incorporation of passive solar systems in buildings, such as horizontally and vertically shading systems and a more accurate study of the HVAC system loads to use.

2 Steps to Perform in a Building Energy Simulation

There is an increasingly range of energy simulation software tools available, with the ability to calculate increasingly complex energy requirements, with more variables and a more rigorous approach. Generally speaking in all energy simulation software tools there are three steps that have to be performed in a building simulation.

2.1 First Step - Creation of a Building

The creation of the building is the earlier stage of an energy simulation. This process can be done for example by inserting the coordinates in the software tool such as in Energy Plus simulation software (Figure 1) or by uploading files from other software, such as AutoCAD or Google Sketch Up. The introduction of coordinates is performed according to a certain reference (which is located in a pre-determined position).

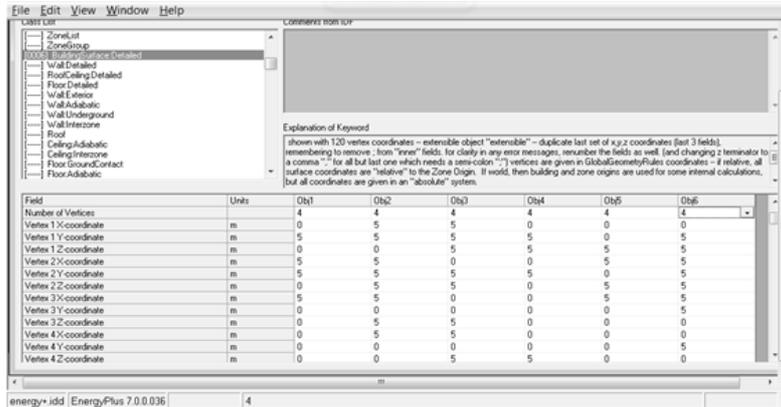


Fig. 1. Introduction of coordinates of a cube in the option "Detailed Surface Building" of EnergyPlus

After this procedure, it is possible to see the figure introduced in the software tool through the DXF button (Figure 2) that connects to AutoCad and which allows to view it in this format (Figure 3).

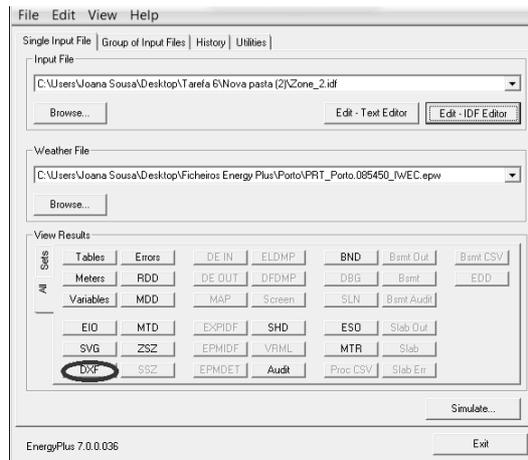


Fig. 2. DXF button in the EnergyPlus.

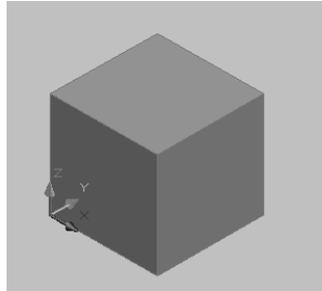


Fig. 3. Results of Coordinate Insertion in EnergyPlus.

Concerning the structure of the building and its construction, it is essential to specify the dimensions of the organizational structure, geometry and materials used in the components of the building architecture (Figure 4). The development of the model based on the characteristics mentioned above represent the building itself ready to be computed.

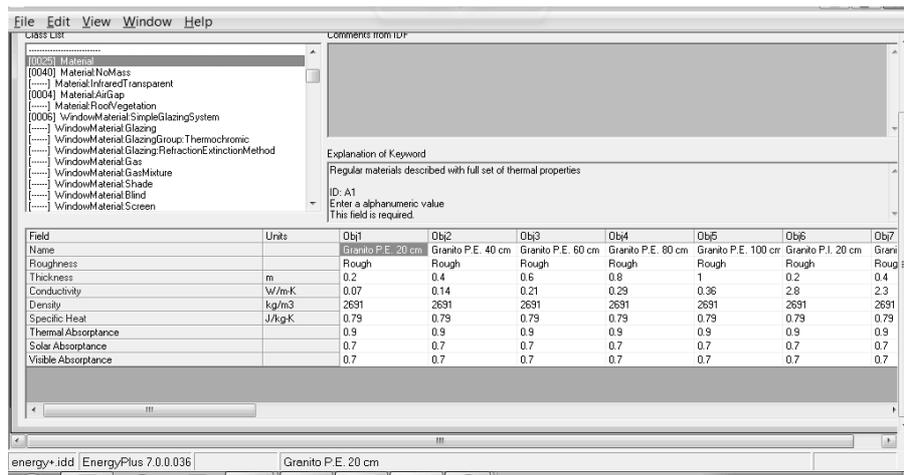


Fig. 4. View of the Interface to the Introduction of the Materials in Energy Plus.

2.2 Second Step - Building Simulation

In this step, it is established which variables are to consider in the simulation of the building and make the software tool run.

The thermal performance of the building can vary according to its use. Therefore it is important to specify the type of building (office, housing, etc.), the human activities carried out, the existing equipment (lighting, refrigeration, air conditioning systems, furnaces, etc.), and their daily schedules (Figure 5). The description of these parameters allows establishing the internal heat load and ventilation (Figure 6).

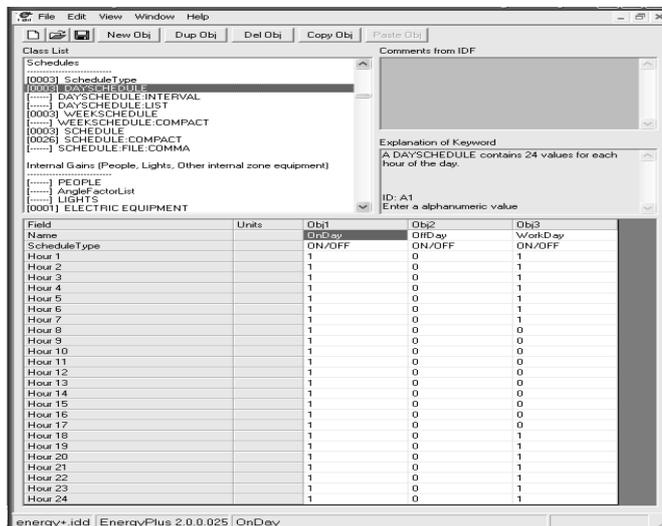


Fig. 5. View of the Interface to the Introduction of Schedules in Energy Plus.

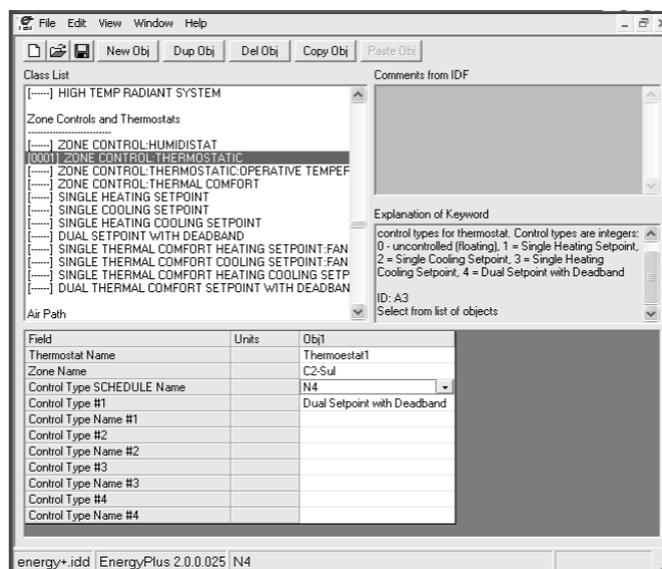


Fig. 6. View of the Interface to the Introduction of Thermostat Definitions in Energy Plus.

2.3 Third Step - Analysis of Results

After running the software tool, it should be checked if there are any error or severe mismatch introduced in the variables set. In some cases the simulation software tool issues its own warnings in a final report containing the results from which should be retained all the relevant conclusions.

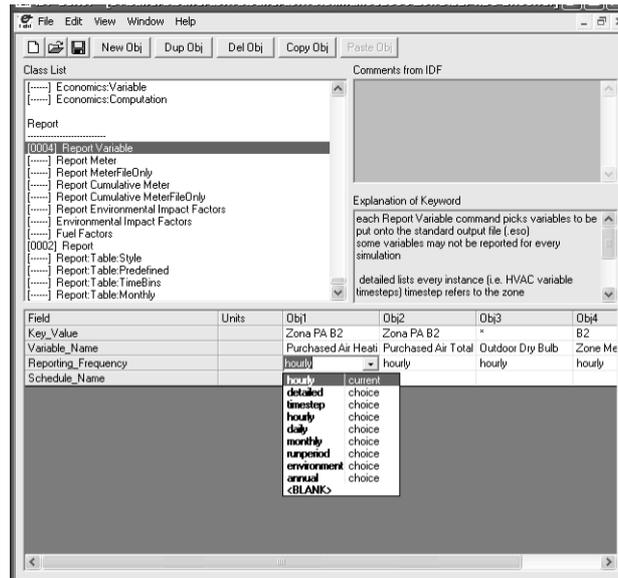


Fig. 7. View of the Report Variable Definitions in Energy Plus.

Depending upon the simulation software tool of energy it is used, the following aspects should be considered:

- Physical Phenomena: Hygrothermal behavior, artificial/natural illumination, acoustics, ventilation and air distribution;
- Energy Systems: Modeling energy in a building, heating and cooling, thermal mass, cogeneration and renewable energy;
- HVAC Systems: Thermal loads and its forecast for optimizing control of components and modeling systems, dynamic behavior and control systems, environmental quality and energy consumption;
- Human Factors: Comfort, visual modeling and indoor air quality;
- Urban Simulation: Sunlight and shadow effects.

In each building simulation there are four fundamental aspects that must be taken into account:

- Structure of the building and its organization;
- Physical phenomena involved in the simulation;
- Weather conditions;

- Use of the building.

In relation to physical phenomena, the model seeks to describe the physical behavior of building materials and their components, and their performance on the transfer of heat by conduction, convection and radiation.

3 Presentation of Some Energy Simulation Software tools

3.1 Energy Plus

Energy Plus is one of the most known energy simulation software tools. Its development began in 1996, sponsored by the Department of Energy (DOE) from United States of America (USA) [5]. Initially, the U.S. government was developing two different software tools, BLAST and DOE-2, which were abandoned after many discussions and represented a first step and the working basis of the Energy Plus. The Energy Plus has the features and capabilities of BLAST and DOE-2, however is an entirely new software tool that combines the heat balance of BLAST with a generic HVAC system. The Energy Plus aims to develop and organize software tools in modules that can easily work together or separately. It is important to outline that in Energy Plus does not exist a visual interface that allow users to see and concept the building. In this case third-party software tools, i.e., Design Builder need to be used. Energy Plus is a thermal simulation software tool that allows the analysis of energy throughout the building and the thermal load and it is used by engineers, architects and researchers to model the energy use and water use in buildings. The software tool simulates models for heating, cooling, lighting, ventilation, other flows of energy and water use. The simulation of a building is divided into two stages [5, 6, 7, 8]:

- Construction of the building;
- Introduction of data, such as environmental aspects, effects of shading, cooling system, internal gains, etc.

3.2 ESP-r (Energy Simulation Software tool)

The software tool ESP-r (Energy Simulation Software tool) is intended to support the construction project with regard to energy and environmental performance, in a realistic and accurate way. The software tool is a mathematical software for a project manager that coordinates the data, simulation, CAD applications, different tools for evaluating performance, display and report generators, etc.. The ESP-r uses several complex equations to deal with all aspects at the same time (geometry, construction, operation, distribution, heat dissipation, etc.). These equations are integrated in successive time steps in response to the influences of the occupants, and climate control systems. The geometry of the building can be set in CAD software tools or other similar tools to allow the specification of the geometry of buildings. The models created in this software can be exported to Energy Plus [9, 10].

The operating conditions are determined through database support. Shading, insulation, HVAC systems, areas of computational fluid dynamics (CFD), electricity, re-

newable energy embedded systems, lighting, natural ventilation, combined heat and power generation, facades photovoltaic systems for control of indoor air quality can also be included in the models pre-determined. The time simulation of the building with ESP-r simulation tool can vary in a range from one minute to one hour. The outputs of the simulations can be viewed by the interactions between the domains of assessment or exported to other graphics software. The ESP-r is extremely useful and is a powerful tool to simulate many innovative technologies. However, the program requires a great knowledge and expertise from its users, and requires a long learning process.

3.3 IDA ICE

The thermal simulation software tool IDA Indoor Climate Energy is based on a general system simulation platform with a modular system. The multi-domain physical systems are described in the IDA using symbolic equations starting with a simulation language Neutral Model Format (NMF - Neutral Model Format). The user defines the tolerances which control the accuracy of the solution, thus allowing the isolation of numerical modeling approaches []. End-user has the following advantages:

- Extensions can be added to the initial model;
- The mathematical model can be inspected to investigate the variables, parameters and equations;
- The research models are easily performed.

3.4 IES VE (Integrated Environmental Solutions - Virtual Environment)

The simulation software tool IES provides the design professionals with a variety of variables in simulation analysis of buildings. The model works on the geometric representation that represents the building. The software tool allows interaction with other energy simulation software tools. The simulation software tool incorporates a tool for dynamic thermal simulation of heat transfer processes of buildings, which is the ApacheSim. The simulation software tool was tested using the IES ASHRAE 140 and is qualified as a dynamic model in CIBSE system of classification. The software tool provides an environment for the detailing of the building systems, allowing their optimization taking into account criteria such as comfort and energy. The dynamic tool ApacheSim can be dynamically linked to the Macro FLO dynamic tool for natural ventilation and HVAC Apache dynamic tool to perform analysis of air leaks and for analysis of natural lighting and shading. The results should be automatically exported.

3.5 TRNSYS

TRNSYS is a transient system simulation software tool with a modular structure that has been specially designed to develop complex systems related to energy, outlining the problem in a number of smaller components [11]. The components ("Types") may range from simple heat pump to a multi-zone of a building complex. The components

are configured through the graphical user interface known as TRNSYS Simulation Studio. In the simulation software tool energy TRNSYS the construction of the building can be achieved by the introduction of data on dedicated visual interface, known for TRNBuild [5].

The software tool sets the time intervals which may vary from 15 minutes to an hour, but may be able to perform simulations in the time interval of 0.1 seconds. The library software tool in addition to a multi zone, allows the use of many commonly used components, including: solar panels, photovoltaic systems, HVAC systems, cogeneration systems, hydrogen, among others. It also allows the creation of routines to manipulate weather data and other data by changing the simulation results. The modular nature of this software tool facilitates the addition of mathematical models to the software tool. The components can be shared among multiple users without having to recompile the software tool due to the use of DLL technology. In addition, this energy simulation software tool allows the user to incorporate other components developed in software tools such as Matlab, Excel, VBA, etc.. Moreover, the software tool includes the possibility of adding HTML views through a software tool called TRNSED, which enable non-users to view and do parametric studies of TRNSYS files, in a simplified representation of a web page.

4 Comparison of Energy Simulation Software tools

Each software tool of the mentioned energy simulation software tools has certain characteristics, and specific applications [12]. In order to better understand specific features of each one, Table 1 presents a summary table of the features of each of the software tools mentioned above, in particular: Solution of Simulation; Duration Calculus; Geometric Description; Renewable Energy Systems; Electrical Systems and Equipment; HVAC systems.

5 Conclusion

Along with materials and construction techniques also energy simulation software tools of buildings have had developments over the years. Currently there are several energy simulation software tools with different levels of complexity and response to different variables. Among the most complete simulation software tools are the Energy Plus, the ESP-r (Energy Simulation Software tool), the IDA ICE (Indoor Climate Energy), IES-VE (Integrated Environmental Solutions - Virtual Environment) and TRNSYS. Being the most complete software tools, these are also the most complex and therefore require greater expertise.

From the analyzed energy simulation software tools, TRNSYS is the most complete, but depending on the user perspective and final purpose the other software tools could be more appropriated. The major limitation of TRNSYS is to not being able to connect with AutoCad Software tool for importation and exportation of files. In this aspect Energy Plus, ESP-r and IDA ICE are more appropriate.

Table 1. Comparison of Features of Various Simulation Software tools [5].

	Energy Plus	ESP-r	IDA ICE	IES	TRNSYS
Simulation Solution					
Simulation of loads, systems and solutions	X	X	X	X	X
Iterative solution of nonlinear systems	X	X	X	X	X
Duration of Time Calculation					
Variable time intervals per zone for interaction of the HVAC system	X	X			
Simultaneous selection of building systems and user		X	X	X	X
Dynamic variables based in transient solutions	X	X	X		
Complete Geometric Description					
Walls, roofs and floors	X	X	X	X	X
Windows, skylights, doors and external coatings	X	X	X	X	X
Polygons with many faces	X	X	X	X	
Imports of building from CAD programs	X	X	X	X	X
Export Geometry of Buildings for CAD software	X	X	X		
Import / Export of simulation models of programs	X	X	X	X	
Calculation of thermal balance	X	X	X	X	X
Absorption / release of moisture from the building materials	X		X	X	X
Internal thermal mass	X	X	X	X	X
Human thermal comfort	X	X	X	X	X
Solar Analysis	X				X
Analysis of Isolation	X	X	X	X	X
Advanced fenestration	X	X	X	X	X
Calculations of the building in general	X	X		X	X
Surface temperatures of zones	X	X	X	X	X
Airflow through the windows	X	X	X	X	X
Driving surfaces	X	X	X	X	X
Heat transfer from the soil	X	X	X	X	X
Thermophysical variable			X		
Daylighting and lighting controls	X	X	X	X	
Infiltration of a zone	X	X	X	X	X
Automatic calculation of coefficients of wind pressure				X	
Natural Ventilation	X	X	X		X
Natural and mechanical ventilation				X	X
Control open of windows for natural ventilation	X	X	X		X
Air leaks in multiple zones	X	X	X		X
Renewable Energy Systems					
Solar Energy	X	X		X	X
Trombe Wall	X	X	X	X	X
Photovoltaic panels	X	X		X	X
Hydrogen Systems		X			X
Wind Energy		X			X
Electrical Systems and Equipment					
Energy Production through R.E.	X	X			X
Distribution and management of electric power loads	X	X			X
Electricity generators	X				X
Network connection	X	X			X
HVAC Systems					
HVAC idealized	X	X	X	X	X
Possible configuration of HVAC systems	X	X	X	X	X
Repetitions cycle air distribution systems	X	X	X	X	X
Modeling CO ₂			X	X	X
Each distribution of air per area	X	X	X	X	X
Forced air unit per zone	X	X	X	X	X
Equipment Unit	X	X		X	X

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