BCORE: an automated energy simulation and calibration software tool for buildings

BCORE: una herramienta de simulación y calibración energética automatizada para edificación

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Key Words: (Software, simulation, calibration, energy efficiency, building | Software, simulación, calibración, eficiencia energética, edificio)

Abstract: En las últimas décadas, la eficiencia energética en la edificación ha tomado un papel relevante en materia de ahorro energético, tanto a nivel nacional como europeo. De hecho, la certificación energética de edificios es actualmente una exigencia derivada de la Directiva 2010/31/UE y la Directiva 2012/27/UE relativas a la eficiencia energética de los edificios. En este campo, las herramientas informáticas resultan un gran avance y una gran ayuda para la gestión energética de los edificios.

En este trabajo se presenta BCORE, una nueva herramienta automatizada de simulación y calibración energética para edificación. Este software permite que cualquier usuario, sin necesidad de ser experto en el manejo de Tecnologías de la Información (TI), pueda realizar simulaciones energéticas de edificios en un entorno amigable y a través de una interfaz clara e intuitiva. Se trata de una solución innovadora, ya que a través de una aproximación holística este programa integra en una única herramienta, múltiples utilidades y aplicaciones que actualmente no se encuentran disponibles en ningún software comercial del mercado.

El punto de partida de BCORE es un modelo geométrico y constructivo que puede ser importado directamente a la herramienta en formato OpenStudio Model (OSM) o Green Building XML (gbXML). A continuación, el software permite la creación de un modelo energético del edificio completo, Building Energy Model (BEM),

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introduciendo los materiales, muros y huecos, así como las cargas térmicas y los sistemas de producción y distribución de energía del edificio. Una vez el modelo energético del edificio ha sido completado, simplemente aportando al programa un archivo meteorológico en formato EnergyPlus Weather (EPW) de la zona en la que se encuentra el edificio, se puede simular automáticamente el edificio. El motor de cálculo utilizado en la simulación es TRNSYS. Es prácticamente imposible que una primera simulación se acerque con exactitud al comportamiento real de un edificio. Es aquí donde el software desarrollado aporta un mayor avance e innovación en materia de simulación energética permitiendo la calibración automatizada del modelo. En la actualidad no existe ningún software en el mercado que permita calibrar automáticamente el modelo energético de un edificio. Esta calibración se realiza con GenOpt, un programa de optimización que minimiza la función de coste definida, y utilizando datos reales de monitorización, obteniendo resultados altamente realistas. Además, se están desarrollando nuevos métodos de calibración para ser implementados en dicha herramienta y conseguir así un modelo energético prácticamente idéntico a la realidad. Otro punto novedoso de la aplicación es la posibilidad de implementación de Medidas de Conservación de Energía (MCE) que permiten llevar a cabo la parametrización del modelo para simular cambios en la envolvente, la realidad de uso o los datos meteorológicos y de este modo mejorar el comportamiento energético del edificio. Finalmente, la aplicación permite mostrar los resultados de temperaturas, potencias y demandas, tanto del proyecto base como de las MCEs, permitiendo al usuario, a través de evaluaciones técnicas y económicas, gestionar eficientemente el edificio.

1. INTRODUCTION

Energy efficiency has become a key topic for the European Commission. Using energy more efficiently not only saves energy, but also helps to protect the environment and reduce reliance on fossil fuel external suppliers. On the other hand, buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the European Union. Currently, the European buildings are characterized by their aging, where about 35% of buildings are more than 50 years old. These old buildings can consume up to 5 times more energy than modern buildings designed and built in a much more efficient way. It is estimated that improving energy efficiency in the current building stock could reduce between 5 to 6% of the energy consumed and up to 5% of the CO_2 emissions into the atmosphere [1].

The main directive on energy efficiency in buildings is Directive 2010/31/EU on energy performance of buildings [2]. In November 2016, the European Commission proposed an update of this Directive to help promote the use of intelligent technology in buildings and simplify existing standards. Under this directive all buildings in the European Union are obliged to include an energy performance certificate when announcing their sale or rental. In addition, all buildings must be "nearly zero energy buildings" by December 31, 2020. However, public buildings must already comply with this measure in December 31, 2018. Minimum energy requirements are also established for new buildings, for renovations and for the replacement of building elements such as heating and

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cooling systems, roofs, walls, etc.

Considering that the European regulations on energy efficiency in buildings are becoming more stringent and restrictive, all the tools that facilitate achieving these objectives are a breakthrough. Thus, computer simulation tools can greatly help to improve the energy management of existing buildings and predict the energy performance of those buildings in the design phase. In this respect, BIM (Building Information Modeling) should not be confused with BEM (Building Energy Modeling). BIM is defined as a shared digital representation of the physical and functional characteristics of any constructed object that provides a reliable basis for decision making [3]. It is a collaborative work methodology for the creation and management of a construction model, which is composed of the design phase, the execution of the project and the entire life cycle of the building. This BIM philosophy was extended to energy efficiency and emerged the BEM. The BEM is the practice of using simulation software in the energy analysis of a building [4]. The simulation software works by running a mathematical model that provides an approximate representation of the building. BEM tools play a very important role in building design and optimization. BEM can be used to implement energy saving or retrofitting measures, to certificate buildings or to control and analyse the building energy efficiency. In addition, the use of BEM tools entails several benefits such as the reduction of operating costs in new construction projects and in rehabilitation projects as well as the improvement of the comfort feeling of the building occupants.

There are many BEM tools each with different capabilities and applications. Crawley et al. [5] published a complete report *"Comparing the capabilities of building energy performance simulation programs"* comparing characteristics and capabilities of the 20 most important BEM tools: BLAST, BSim, DeST, DOE-2.1E, ECOTECT, Ener-Win, Energy Express, Energy-10, EnergyPlus, eQUEST, ESP-r, IDA ICE, IES <VE>, HAP, HEED, PowerDomus, SUNREL, Tas, TRACE and TRNSYS. The authors conclude that even the most mature tools do not have a common language to describe what they can do and that there is a lot of ambiguity about it. In addition, the effort and knowledge that users require to master the management of these tools is often high in most cases. On the other hand, due to the complexity of a building environment and the influence of multiple independent interacting variables, it is difficult to achieve a real representation of the building's behaviour. By adjusting the model results with some measured data, we can obtain more accurate and reliable results. This adjustment of the model outputs with the measured data is known as calibration [6]. And as for the calibration in commercial tools, it is verified the patent lack of integrated tools and automated methods that could help the calibration [6].

Trying to fill in the two most important weaknesses observed in the energy simulation tools, the difficulty of use and the calibration of the models, BCORE tool, an own development software was born. It is a new automated building energy simulation and calibration tool. This software allows any user, without having to be an expert in the management of Information Technology (IT), to perform building energy simulations in a friendly framework and through a clear and intuitive interface. This is an innovative solution, since through a holistic approach this

program integrates into a single tool, multiple utilities and applications that are currently not available in any commercial software of the market. Among these software capabilities, the automated calibration of the simulations highlights, allowing to obtain highly realistic models.

2. BCORE: AUTOMATED SIMULATION AND CALIBRATION TOOLCIÓN AUTOMATIZADA

2.1. OVERVIEW

BCORE is an own development BEM tool. It is presented as a web application so only internet connection and a web browser is needed to use it. This software allows the automated simulation and calibration of a building. In addition, it presents a simple framework and easily usable by any end user without needing to be an IT expert. Currently the program is available in two different languages, English and Spanish. The operation of the program is based on the introduction of the building model, its geometry, enclosures, thermal loads and energy generation and distribution systems. This building data as well as weather data from the building site in EnergyPlus Weather (EPW) format are necessary for the simulation. To simulate, TRNSYS, a program that simulates the behaviour of transient systems, is used as calculation engine. Normally, a first simulation does not produce realistic results, there are always discrepancies between the results of the simulation and the real data. A model that is not realistic is completely useless, it is useless to analyse the building energy performance. At this point, it is where the software presents its main contribution, which is the ability to automatically calibrate the building model. For this, real building monitoring data, consumption, temperature and relative humidity are used. This calibration is done through GenOpt optimization software. Once simulated and calibrated the model, BCORE presents results of temperature, power and demand depending on the month of the year or the thermal zone. Another strength of the software lies in the ability to define different Energy Conservation Measures (ECM) that can be compared with the base project. In Figure 1 the general operation of BCORE software can be observed through a diagram.

Fig. 1: Overall operating scheme of BCORE software

2.2. BUILDING MODEL DEFINITION

The starting point of the BCORE software is a geometric and constructive model of the study building that can be imported directly into the tool in OpenStudio Model (OSM) or Green Building XML (gbXML) format. The building must be divided into thermal zones. A thermal zone is the basic unit in the model of a building, and can correspond with a space or room or with several spaces or rooms. To open a new project in BCORE, it is only necessary to drag the file of the geometric model to the browser screen in which the program is open. Next, the software allows the creation of an energy model of the complete building through the tab "Building" where the user can enter the rest of the necessary data prior to the simulation. As shown in Figure 2, data on general

parameters of the building, on materials, walls and openings, i.e. doors and windows, are completed in the tab of the building. Thermal loads and energy generation and distribution systems are also introduced, and the elements and schedules of the model can be observed. In general parameters information about the floors, the building orientation, characteristics of the ground and the model of infiltrations calculation can be completed. The infiltration models can be the k1 k2 k3 model, Laurence Berkeley Laboratory (LBL) model or the Sherman-Grimsrud model.

Fig. 2: "Building" tab in BCORE

In addition, as discussed above, the user can define each thermal load that the building under study supports as well as their schedules in the "Thermal zones" tab. In particular, infiltrations, occupancy, lighting, equipment, heating, cooling, ventilation and comfort, as can be observed in Figure 3. For each of the thermal loads it is possible to define an specific schedule using of a very intuitive graphic system in which the user can establish within a same schedule different ranges depending on the time of the year or for example if it is weekend or holiday. In addition, different schedules can be defined in the different thermal zones in which the building is divided. It is also possible to introduce thermal bridges on surfaces if necessary. The entire project can be saved and the saved file has .bcore format, an own format of the application.

Fig. 3: "Thermal zones" tab in BCORE

2.3. BUILDING SIMULATION AND CALIBRATION

Once the model of the building is completely defined the user can proceed to its simulation. The calculation engine is TRNSYS [7], a transient simulation software with a modular structure formed by components called "Types". The TRNSYS models are open source and the "Types" are used to model the multiple zones of a building and HVAC systems [8]. These components are organized through a graphical user interface called TRNSYS Simulation Studio and the construction of the building can be done with the introduction of data in a visual interface known as TRNBuild [9]. In addition, TRNSYS integrates a library known as TESS library that includes more than 500 "Types". The user of BCORE does not need to know the operation nor to handle TRNSYS, a program very precise and complete but very complicated to use.

Before starting the simulation, the output folder of the results is selected, the weather file of the place where the building is located is inserted in EPW format, the duration of the simulation indicating date and time of start and end of that simulation, the simulation timestep and the outputs of simulation. These outputs can be temperature, comfort and energy balance. If energy generation and distribution systems have been selected, it is possible to choose more outputs such as fuel consumption, electrical power consumption, distribution system demand, distribution system losses and equipment status. The user can also indicate the holiday schedule so that the

simulation is as accurate as possible. The simulation is performed automatically and the user can observe the progress of the simulation on the screen as shown in Figure 4.

Fig. 4: Progress screen of a simulation

As mentioned previously, usually the simulated building does not behave in the same way as the real building does. There is a difference between the actual behaviour of the building and the result of the simulation. Therefore, the building model needs to be calibrated. Calibration is necessary to reduce these discrepancies between simulation results and actual data. Many studies have found this difference between the results of simulated models and the actual energy consumption of a building, reaching differences of up to 100% [10]. This undermines confidence in the predictions of the model and reduces the use of BEM tools during the design, start-up and operation of the building, since for these tools to be used with a certain degree of confidence, it is necessary that the existing model represents more properly the actual behaviour of the building under study [6]. Calibration in BCORE is automated and performed using the GenOpt optimization tool, which uses a search algorithm to generate the optimum calibration option. The first step of the calibration is the introduction of the actual data that can be the annual energy consumption in kWh, the relative temperatures or humidities of the different thermal zones of the building. Temperature and relative humidity data can be entered into text files in Comma Separated Values (CSV) or TXT format. Once the available monitoring data has been entered, the calibration is set by selecting the actual data to be used and the parameters to be calibrated. These parameters can be the layer thickness, the schedules of any of the thermal loads of the building, the glasses or the thermal bridges. The calibration is performed automatically and the program calculates and performs the necessary simulations by varying the considered parameters until obtaining an optimal solution. In this process, the cost function is minimized by varying the parameters to be calibrated between the specified values. The program also calculates the errors obtained before and after the calibration. The ASHRAE Guideline 14 [11] establishes that a complete building can be considered calibrated when the model has a Normalized Mean Bias Error (NMBE) of less than or equal to 5% and a Coefficient of Variation of the Root Mean Square Error (CV(RMSE)) of less than or equal to 15% relative to monthly data. If the sampling data are hourly, these requirements should be 10% and 30%, respectively. On the other hand, new calibration methods are being tested and developed to be implemented in BCORE tool and thus to achieve an energy model practically identical to reality.

2.4. ENERGY CONSERVATION MEASURES AND RESULTS PRESENTATION

Once the building model is calibrated and behaves as the actual building, it can already be used to implement ECM. These ECMs allow to carry out parameterization of the model and simulate changes in the enclosure of the building as well as in the reality of use or in the meteorological data. The objective of simulating these ECMs is to improve the building's behaviour and achieve energy savings. For this purpose, BCORE has a section in

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which the user can introduce different measures and calculate the energy savings obtained. In the following Figure 5 an overview of the possibilities of ECM that the program presents, and in particular a change of window can be observed. In addition, measures can be implemented by modifying the building's general construction characteristics, its degree of tightness, the materials of any of the building's walls, complete walls, windows or only the glass. The user can also modify the schedules of the thermal loads, the multiplier factor of the schedule or the complete schedule.

Fig. 5: ECM tab in BCORE

Once the simulation of the base project and the parametric simulations of the ECMs is finished, a folder is generated with the output files of the project that are then loaded into the program. BCORE displays the results in the "Results" tab, which depend on the outputs previously selected in the simulation. The results of temperature, power and demand can be shown in general, by floor or by thermal zone. In addition, the results are represented in bar, line or circular graphs. The program also allows the download of the demand results in a separate file that can then be processed by the user.

3. BCORE APPLICATION: CASE STUDY IN A SCHOOL

The degree of development of the BCORE tool is very high and its application in the market can be immediate. To demonstrate its potential and to validate its operation a complete example applied to a school in A Coruña, Galicia, Spain, is presented below. The school is modelled, simulated, calibrated and ECM are applied to it as explain next. The purpose of the case study is also to show the ease of use of the program and interface appearance.

The first step is to generate the geometric model of the building to be able to enter it into the program. The geometric model of the school is made in SketchUp with the OpenStudio plug-in as shown in Figure 6. The generated file is an OSM and in order to open it with BCORE, it is only necessary to drag it to the web browser window, as BCORE is a web application. The model is a building formed by 9 thermal zones, with 192 surfaces and 120 sub-surfaces, i.e. doors and windows.

Fig. 6: Geometric model of the building done using SketchUp and the OpenStudio plug-in

Next, the model of the building is completed, starting with the general parameters in which the heat transfer with the ground is determined, in particular a totally isolated adiabatic ground is established and the model k1, k2, k3 for the infiltrations calculation is set. This model of calculation consists of an empirical method that estimates the exchange of air per hour depending on the level of tightness of the building, the ambient temperature, the room temperature and the wind speed. The materials are then established. The geometric model usually brings some predefined materials defined in the building design, but new materials can also be defined or imported from

predefined libraries available to the BCORE user. In order to define a new material it is necessary to know its properties, namely its heat capacity (J/kg), its conductivity (W/m·K) and its density (kg/m^3). It is also necessary to know its thermal resistance (m^2·K/W) if it is a material without mass. The program allows the definition of the walls and openings of the building. Table 1 shows the types of surfaces that make up the school and in Table 2 the type of sub-surfaces present in the school.

Table 1: Walls properties of the building

NAME	U (W/m^{2}K)	TOTAL THICKNESS (m)	MATERIAL	LAYER THICKNESS (m)
Brick vertical roof	3.14	0.17	Mortar cement lime	0.015
			Simple air brick	0.04
			Vertical air chamber	0
			Double air brick	0.08
			Mortar cement lime	0.015
			Ceramic slate or tile	0.02
Vertical roof	3.35	0.15	Mortar cement lime	0.015
			Simple air brick	0.04
			Vertical air chamber	0
			Double air brick	0.08
			Mortar cement lime	0.015
Roof	31.33	0.015	Asbestos cement	0.015
Roof slab	3.63	0.25	Unidirectional slab	0.25
Mortar façade	3.35	0.15	Mortar cement lime	0.015
			Simple air brick	0.04
			Vertical air chamber	0
			Double air brick	0.08
			Mortar cement lime	0.015
Brick façade	3.14	0.17	Mortar cement lime	0.015
			Simple air brick	0.04
			Vertical air chamber	0
			Double air brick	0.08
			Mortar cement lime	0.015
			Ceramic slate or tile	0.02
Slab	3.19	0.30	Stoneware 2600 d 2800	0.02
			Mortar cement lime 1400 d 1600	0.03
			Unidirectional slab	0.25
Floor	20	0.1	Poured concrete 2300 d 2600	0.1
Partition	4.80	0.11	Mortar cement lime	0.015
			Double air brick	0.08
			Mortar cement lime	0.015
Air slab	2.91	0.33	Stoneware 2600 d 2800	0.02
			Mortar cement lime 1400 d 1600	0.03
			Unidirectional slab	0.25

Mortar cement lime 1400 d 1600	0.03

Table 2: Openings properties of the building

NAME	GLASS	FRAME (%)
Exterior door 1	Planilux6mm	60
Exterior door 2	Planilux6mm	30
Exterior window 1	Planilux/Air/Planilux4/6/4	25
Exterior window 2	Planilux6mm	25

Next, as explained above, each thermal load of the building is completed as well as the schedules of such loads in infiltrations, occupancy, lighting, equipment, heating, cooling, ventilation and comfort. In this case the schools do not have cooling system and the heating demand is calculated as an ideal system. The program allows to use energy generation and distribution systems or calculate the ideal heating demand. In the latter case a heating system is not calculated but the desired temperature is maintained in each thermal zone indicated in the schedule.

After completing the model and before carrying out the first simulation, a weather file from A Coruña is introduced, which is the location of the school, and of the year 2015, which is the entire year that is simulated. Next, the full year is simulated and the annual demand resulted in 20,216 kWh/year as observed in results. It is known as data that the annual consumption of the year 2015 was of 26,048 kWh/year, reason why this data is used to calibrate. The parameter to be calibrated is the infiltrations, since it is a very complicated parameter to know a priori in a building because of the difficulty of its measurement. Therefore, the infiltrations of the school are calibrated and in Figure 7 the calibration result can be observed. The initial value 1 of the multiplier factor of the infiltrations is replaced by the calibrated value 2.5875. The initial error value of the model 28.84% and the final value of the error 0.04% are also observed.

Fig. 7: School calibration results using annual consumption

Once the model of the building is calibrated, the actual behaviour of the building is known and therefore it is possible to simulate modifications in the enclosures, in the use, in the equipment, etc. and to analyse whether these changes involve an energy saving or an improvement in the energy management of the building. Several ECMs of the school are simulated, the replacement of one type of window by another, the installation of double glazing, the insulation of the façade and the insulation of the roof. The program simulates the different measures in a parametrically and allows to observe the results graphically comparing the different ECMs with respect to the base project. For example, Figure 8 shows the monthly energy demand during the year 2015 for the base project and for the ECM 1 that was the replacement of one type of window by another. It can be observed that in all months the demand for heating is lower for the ECM than for the base project.

Fig. 8: Monthly heating demand of the base project and ECM 1

4. CONCLUSIONS

This article presents BCORE, an automated energy simulation and calibration software for building. The program is at an advanced stage of its development and has proved to be a very useful tool and with important advantages over other commercial programs available. The main differentiators of this software compared to other programs are:

- First and foremost, it is the automated calibration of the simulation, allowing to obtain highly realistic results.
- Incorporation of predefined and expandable libraries of materials and enclosures for any type of building.
- Provision of different infiltration models that calculate loads using statistical techniques.
- Parameterization of the model to simulate changes in the building enclosures, the reality of use or the weather data through the implementation of ECM, which allow the user, through a technical evaluation, to manage the building efficiently.
- Incorporation of predefined basic energy generation and distribution systems in a building.
- Friendly framework, clear and intuitive interface.

ACKNOWLEDGEMENTS

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