IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

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To cite this article: J P Carvalho *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **225** 012072

View the article online for updates and enhancements.

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 642384.



Using BIM to optimise and assess the energy efficiency category of SBTool^{PT}-H

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Abstract. The current method for assessing the two indicators of the Energy Efficiency category of the Building Sustainability Assessment method SBTool^{PT}-H (P7: Primary energy, P8: In-situ energy production from renewables) is rather time-consuming. The assessment requires many values that need to be calculated manually or with specific spreadsheets, whenever a design is proposed. When a design alteration is introduced, the whole process needs to be repeated, which leads to designers to be discouraged to develop this task. This research explores the use of the Building Information Modelling (BIM) software – Autodesk Revit and Autodesk Green Building Studio (GBS) – to assess the Energy Efficiency category. The purpose is to find a more efficient assessing method, encouraging and supporting designers to optimise their projects. More efficient methods can contribute to more sustainable constructions and to decrease the construction industry's environmental impact. To explore if Revit and GBS can streamline the assessment of this SBTool^{PT}-H category, a case study was carried out. A reference building was created which complied with all the current Portuguese regulations. The reference building was then modelled in Revit and submitted to an energy analysis using GBS. The results showed for indicator P7, that the use of GBS and Revit streamlines the assessment by faster extraction of information thanks to the 3D-model and the energy analysis software. However, the assessment could be made even more efficient if the software and national regulations were more matched such as conformity of units and analysed parameters. Concerning indicator P8, the results showed clearly that using GBS is a rather efficient process.

Keywords: sustainable construction, SBTool, BIM, Building Sustainability Assessment, energy efficiency

1. Introduction

Despite the good structural state of the existing building stock in the European Union (EU), they are still relatively energy inefficient [1]. The EU is aware of this problem and that is why they released the Energy Performance of Buildings Directive [2] in 2002 and published a reviewed version in 2010 [3]. The goal was to create a main legislative instrument aiming to promote the improvement of buildings



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energy performance within the EU. In Portugal, the EPBD was transposed in 2013, by the *Regulamento de Desempenho Energético dos Edifícios de Habitação* (REH) [4].

Several entities started developing Building Sustainability Assessment (BSA) methods following the EU's and society's increasing awareness regarding sustainability. These methods aim at implementing and spreading sustainable measures, evaluating and monitoring buildings performance and gathering information to support decision making during the design phase [5-7].

In this study, focus will be put on SBTool^{PT}-H. This BSA method is adapted to Portuguese residential buildings and environment characteristics. The assessment in SBTool^{PT}-H covers 25 sustainability parameters which are organised in 9 categories divided over 25 parameters with different weights according to the national standards and practices. Each parameter is classified with a score that results from the comparison between the analysed building and the national reference. At the end, each parameter is pondered, and a final classification is given to the building [5].

Effectively acting on energy use is an essential path to achieve better, ecological and sustainable buildings. The traditional way of assessing and optimising the energy efficiency of a building in BSA methods is a time-consuming process which can lead to the neglection of design optimisation. Therefore, the opportunity arises to establish a convenient energy efficiency assessment process where design adjustments require less time, consequently turning building optimisation easier and cheaper.

Possible change of this assessment process lies in a computer-based technology called Building Information Modelling (BIM). BIM can be described as a set of policies, processes and technologies which conceive a working methodology to manage the 3D drawing and the project data during the building life cycle [8]. This paradigm change will have impacts and benefits for the construction sector and for the society, as better constructions which require fewer materials, less human and financial resources and operate more efficiently [9].

The energy efficiency assessment and optimisation can be less time-consuming by using 3D-models on which energy efficiency analysis can be performed in a short period of time. According to several authors [10-12], the possibility to overlap multidisciplinary information in a single model allows to introduce sustainable measures and make energy performance analysis during the project life cycle. Azhar and Brown [13] state that the use of BIM to produce sustainable buildings could represent 20% savings in the building total cost. By implementing results from energy analysis software into BSA methods it could be possible to get an assessment in a more efficient way of leading to more efficient buildings.

The main objective of this study is to optimise the assessment procedure of the energy efficiency category of the SBTool^{PT}-H method with the use of BIM. To date, this method is still relatively complex and time-consuming, and it could be improved with the use of BIM. In this research, the energy efficiency category (C3) of SBTool^{PT}-H will be explored, namely *P7 – Primary energy* and *P8 – In-situ energy production from renewables*. By gathering the necessary data from the BIM model and analysis, an assessment level expressed by letters ranging from 'E' to 'A+' will be achieved for both parameters. REH method will be used to compare the accomplished results, as well as to calculate the reference energy values.

2. Methodology and Case Study

To use BIM to improve the assessment of SBTool^{PT}-H mentioned energy efficiency parameters, a case study was selected and modelled in Autodesk Revit and simulated in Autodesk Green Building Studio. As SBTool^{PT}-H focuses on Portuguese dwellings, the case study characteristics were based on the existing Portuguese building stock. A two-story house located in Porto was selected to verify the applicability and to display the ease or difficulty of the assessment using BIM. The building-design comply to REH requirements and to average net floor areas and non-opaque surfaces of newly built houses in Portugal. The building model is presented in Figure 1 and the construction details are presented in Table 1.

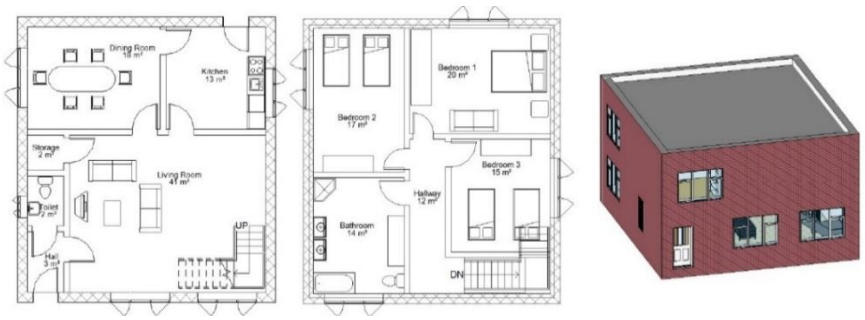


Figure 1. Building Model.

Table 1. Reference model characteristics.

Windows	Low-E Double Glazing (U= 2,2121 W/(m².K)
Doors	Timber flush-panel hollow core (U= 2,3256 W/m².K)
Exterior walls	Double brick wall with 5cm of XPS (Utot= 0,2907 W/(m².K))
Roof slab	Concrete Hollow Slabs with 10cm of XPS (Utot= 0,3309 W/(m².K))
Floor slab	Concrete slab with 8cm of XPS (Utot= 0,4182 W/(m².K))
HVAC system	PTHP, ASHRAE 90.1-2007, 11 EER, Electric Heat
DHW system	Domestic HW Heater (on-demand, 0,85 Energy Factor)

Materials characteristics were defined in Autodesk Revit based on ITE50 from LNEC [14]

The research methodology (Figure 2) consisted in comparing both simulation results from GBS with the traditional method for calculating Portuguese buildings energy performance, using a specific spreadsheet (Version V2.19 of 08 March 2016), created by the University of Coimbra and ITeCons [15] which is according to the REH method [4].

After the energy simulation on GBS, the results were converted on a self-made spreadsheet because they are more extensive than the necessary for SBTool^{PT}-H, which only require energy needs for space heating (Nic), space cooling (Nvc) and the production of Domestic Hot Water (DHW) (Qa). Additionally, GBS does not calculate primary energy needs (Ntc), so the conversion factors defined in REH were also considered to calculate Ntc.

After this, the global primary energy needs for this design according to the conventional practice (Nt) and the global primary energy needs for the case study (Ntc), as well as heating and cooling needs, were calculated using the ITeCons [15] spreadsheet.

With all the energy data, both Ntc values (from GBS and from REH method) were compared and an assessment on the SBTool^{PT}-H energy efficiency category was obtained for both sustainability indicators.

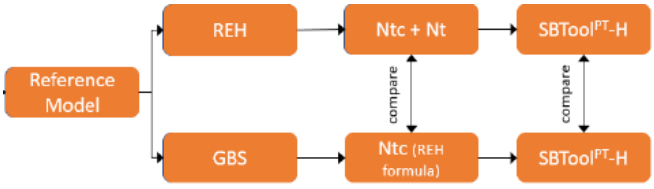


Figure 2. Research methodology.

3. Results and Discussion

3.1. GBS results

With the electricity cost set to € 0,16 per kWh and the fuel (diesel used in the boiler to produce DHW) cost to € 0,02 per MJ [16], the base run of the energy model resulted in an annual energy cost of €1 106. Per year about 5 764 kWh of electric energy and 9 201 MJ (or 2 556 kWh) of fuel (diesel) energy will be used. These results were considered realistic because a prior simulation in an online energy demand

simulator of *Energias de Portugal* (EDP)[17] resulted in the same range of values. A more detailed look to the electric end uses of this base run (Figure 3) shows that space heating, space cooling, miscellaneous equipment and lights are the biggest consumers of electric energy for this case study house. Table 2 presents the Nic, Nvc and Nac values for the simulation model.

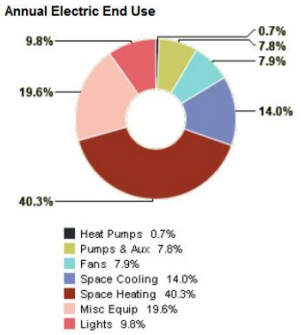


Figure 3. GBS results for electric energy end-uses.

Table 2. GBS results for heating (Nic), cooling (Nvc) and DHW (Nac).

Simulation Model	Nic kWh/m^2	Nvc kWh/m^2	Nac kWh/m^2
	13,58	4,72	14,95

Considering these results and the Ntc-value calculation method based in REH equation (1), the reference model presents a total primary energy use of 29,84 kWhep/m2.year. The conversion factors were based on REH indications.

$$Ntc = \frac{1*Nic}{\eta i} * fpui + \frac{1*Nvc}{\eta v} * fpuv + \frac{1*Nac}{\eta a} * fpua \qquad (1)$$

fpui = fpuv = 2.5 (conversion factor for electricity); fpua = 1 (conversion factor for fuels); ηi = 4,15 (heating system efficiency); ηv = 2,9 (cooling system efficiency); ηa = 0,85 (DHW system efficiency).

$$Ntc = \frac{1 * 13.58}{4,15} * 2.5 + \frac{1 * 4.72}{2,9} * 2.5 + \frac{1 * 14,94}{0,85} * 1 = 29,84\ kWhep/m2.year$$

GBS also considers potential energy produced by photovoltaic cells. This calculation requires the input of the installed panel cost per Watt, the maximum payback period and the electric cost. The installed panel cost per Watt was set to € 1,90 (or € 233,85/m²) for polycrystalline panels in compliance with the cost-calculation website from CYPE Ingenieros [18]. The electric cost was set to € 0,16/kWh and the maximum payback period was set to 10 years. The energy produced by the PV-panels is electrical and can be used for space heating, space cooling, equipment and lighting.

Table 3 presents the results from GBS for renewable energy production. In a situation were 22 m² of PV-panels are installed results in 3 584 kWh/year of electric energy produced, which represents an annual cost saving of € 573.

Table 3. GBS results for PV-panels renewable energy production.

Panel Area (m^2)	Solar Exposure	Obstruction Shading	Annual Energy (kWh/year)	Potential Cost Savings		Payback per Surface (years)
				Per year/m^2	Per year	
15			2 442		€ 391	
17			2 714		€ 434	
22	64.2%	0	3 584	25,90 €	€ 573	8,3
16			2 622		€ 420	
20			3 205		€ 513	

3.2. REH results

The buildings characteristics were introduced in the specific spreadsheet to predict the building energy performance. After defining all the envelope characteristics, as well as location, thermal bridges and

equipment, the results presented in Table 4 were obtained. This spreadsheet automatically calculates the reference value for primary energy, Nt (based on REH requirements) as well as the actual building primary energy performance, Ntc.

Table 4. REH method results.

Nt (from REH)		**Ntc (from REH)**	
Ni (kWh/m^2)	19,65	Nic (kWh/m^2)	19,05
Nv (kWh/m^2)	9,13	Nvc (kWh/m^2)	3,37
Na (kWh/m^2)	13,90	Nac (kWh/m^2)	13,90
Nt [kWhep/(m².year)]	35,37	Ntc [kWhep/(m².year)]	30,78

With all these data, it is possible to compare the results from both GBS software and REH method, presented in Table 5. Note that the results from GBS are based on dynamic simulations and REH results are based on a semi-steady simulation so a certain level of critical analysis is needed. The total primary energy results were quite similar for both methods, with only 1 kWhep/m^2.year of difference. Most notorious differences were reached regarding the heating and cooling needs, with GBS giving less heating needs than REH but more cooling needs. Regarding DHW, a slight but not substantial difference was observed in the value of Nac.

The systems efficiency was set the same as the ones considered for the Nt calculation for GBS results. REH transformation factors (electricity = 0,144 and heating diesel = 0,267) were adopted to determine Nt is kgep/(m².year).

Table 5. REH method and GBS results.

Nt (from REH)		**Ntc (from REH)**		**Ntc (from GBS)**	
Ni (kWh/m^2)	19,65	Nic (kWh/m^2)	19,05	Nic (kWh/m^2)	13,58
Nv (kWh/m^2)	9,13	Nvc (kWh/m^2)	3,37	Nvc (kWh/m^2)	4,72
Na (kWh/m^2)	13,90	Nac (kWh/m^2)	13,90	Nac (kWh/m^2)	14,95
Nt (kWhep/m².year	35,37	Ntc (kWhep/m².year)	30,78	Ntc (kWhep/m².year)	29,84
Nt (kgep/m².year)	7,86	Ntc (kgep/m².year)	6,94	Ntc (kgep/m².year)	6,63

3.3. SBTool^{PT}-H Assessment

P7 – Primary Energy

For this sustainability indicator, five variables are needed to get an assessment. These variables are: the number of bedrooms (3), number of dwellings (1); net floor area per dwelling (171 m²); the annual primary energy demand per net floor area of the dwelling under assessment (Ntc); and the conventional value for the annual primary energy demand per net floor area (Nt) which can be calculated using the mentioned spreadsheet. Figures 4 and 5 presents the necessary data for the assessment of P7, considering GBS and REH results, respectively.

T	Nº F	Ap/F (m^2)	Ap (m^2)	Ntc (kgep/m^2.year)	Nt (kgep/m^2.year)	Best practice	Conventional practice	PENR
T3	1,00	171,00	171,00	6,63	7,86	1,97	7,86	**6,63**
						1,97	7,86	**6,63**

Figure 4. SBTool^{PT}-H P7 input table with GBS results.

T	Nº F	Ap/F (m^2)	Ap (m^2)	Ntc (kgep/m^2.year)	Nt (kgep/m^2.year)	Best practice	Conventional practice	PENR
T3	1,00	171,00	171,00	6,94	7,86	1,97	7,86	**6,94**
						1,97	7,86	**6,94**

Figure 5. SBTool^{PT}-H P7 input table with REH results.

With this information, SBTool^{PT}-H automatically calculates the sustainability score at the level of this parameter, ranging from A+ (best) to E (worst performance). The assessment results using GBS (left) and REH (right) values are displayed in Figure 6. Both have achieved a "level C".

Normalization

$\overline{P_{ENR}} = (P_{ENR} - P_{ENR^*}) / (P_{ENR}^{*} - P_{ENR^*}) =$ 0,21 (P 7.4)

Evaluation

Level	Conditions	(X)
A$^+$	$\overline{P_{ENR}} > 1,00$	
A	$0,70 < \overline{P_{ENR}} \leq 1,00$	
B	$0,40 < \overline{P_{ENR}} \leq 0,70$	
C	$0,10 < \overline{P_{ENR}} \leq 0,40$	X
D	$0,00 \leq \overline{P_{ENR}} \leq 0,10$	
E	$\overline{P_{ENR}} < 0,00$	

Normalization

$\overline{P_{ENR}} = (P_{ENR} - P_{ENR^*}) / (P_{ENR}^{*} - P_{ENR^*}) =$ 0,16 (P 7.4)

Evaluation

Level	Conditions	(X)
A$^+$	$\overline{P_{ENR}} > 1,00$	
A	$0,70 < \overline{P_{ENR}} \leq 1,00$	
B	$0,40 < \overline{P_{ENR}} \leq 0,70$	
C	$0,10 < \overline{P_{ENR}} \leq 0,40$	X
D	$0,00 \leq \overline{P_{ENR}} \leq 0,10$	
E	$\overline{P_{ENR}} < 0,00$	

Figure 6. Results from the assessment of P7 – using GBS figures (left) vs using REH figures (right).

P8 – In-situ energy production from renewables

For this indicator, it is necessary to fill nine variables, namely: the net floor area per dwelling (171 m²); the number of occupants (4); the number of bedrooms (3); The number of dwellings (1); the annual potential energy production from PV-panels (ERen), which can be found in the Photovoltaic Analysis tab in GBS; the annual energy demand for heating (Nic); the annual energy demand for cooling (Nvc); the annual primary energy demand per net floor area of the dwelling under assessment (Ntc); and the conventional value for the annual primary energy demand per net floor area (Nt). Figure 7 and Figure 8 presents the necessary data for the assessment of this sustainability indicator, using GBS and REH results, respectively.

T	NºF	Ap/F (m^2)	Ap (m^2)	Nic (kWh/m2.year)	Nvc (kWh/m2.year)	Qa (kWh/year)	ERen (kWh/year)	Esolar (kWh/year)	Ntc (kgep/m2.year)	Nt (kgep/m^2.year)	Ntc' (kgep/m^2.year)	Ntc" (kWh/m^2.year)	N_{AQS} (kWh/m^2.year)	PER (kWh/m2.year)
T3	1,00	171,00	171,00	13,58	4,72	2556	3584,00		6,94	7,86	82,0	**32,81**	-	**20,96**
											82,037	**32,815**	-	**20,959**

Figure 7. SBTool^{PT}-H P8 input table with GBS results.

T	NºF	Ap/F (m^2)	Ap (m^2)	Nic (kWh/m2.year)	Nvc (kWh/m2.year)	Qa (kWh/year)	ERen (kWh/year)	Esolar (kWh/year)	Ntc (kgep/m2.year)	Nt (kgep/m^2.year)	Ntc' (kgep/m^2.year)	Ntc" (kWh/m^2.year)	N_{AQS} (kWh/m^2.year)	PER (kWh/m2.year)
T3	1,00	171,00	171,00	19,05	3,37	2377	3584,00		6,94	7,86	97,0	**38,80**	-	**20,96**
											97,001	**38,800**	-	**20,959**

Figure 8. SBTool^{PT}-H P8 input table with REH results.

The results for indicator P8 of the SBTool^{PT}-H are presented in Figure 9, considering GBS (left) and REH (right) values. For both, a 'level C' was achieved.

Normalization

(P 8.4)

$\overline{P_{ER}} = (P_{ER} - P_{ER^*}) / (P_{ER^+} - P_{ER^*}) =$ 0,36

Evaluation

Level	Conditions	(X)
A^+	$\overline{P_{ER}} > 1,00$	
A	$0,70 < \overline{P_{ER}} \leq 1,00$	
B	$0,40 < \overline{P_{ER}} \leq 0,70$	
C	$0,10 < \overline{P_{ER}} \leq 0,40$	X
D	$0,00 \leq \overline{P_{ER}} \leq 0,10$	
E	$\overline{P_{ER}} < 0,00$	

Normalization

(P 8.4)

$\overline{P_{ER}} = (P_{ER} - P_{ER^*}) / (P_{ER^+} - P_{ER^*}) =$ 0,27

Evaluation

Level	Conditions	(X)
A^+	$\overline{P_{ER}} > 1,00$	
A	$0,70 < \overline{P_{ER}} \leq 1,00$	
B	$0,40 < \overline{P_{ER}} \leq 0,70$	
C	$0,10 < \overline{P_{ER}} \leq 0,40$	X
D	$0,00 \leq \overline{P_{ER}} \leq 0,10$	
E	$\overline{P_{ER}} < 0,00$	

Figure 9. Results from the assessment of P8 – using GBS figures (left) vs using REH figures (right).

4. Conclusions

Using BIM to assess buildings energy efficiency can be the most efficient and recommendable assessment method. BIM can perform faster analysis and can be considered more reliable since human errors are more avoided. Additionally, extraction information can happen faster, and the designer's decision-making process can be more straightforward. Introducing design changes also requires less time, as it only affects the BIM model and the assessment process can be developed again automatically.

The assessment of P7 can certainly be streamlined using BIM. However, fine-tuning and matching of units between GBS and SBTool^{PT}-H are still needed to optimise the assessment efficiency. However, it already speeds up the assessment process compared to the traditional method. By using BIM, the required values in REH-spreadsheet to calculate Nt and Ntc can be obtained faster. Examples of these are the U-values of building elements, which are automatically calculated and the net floor areas, which can easily be extracted. The assessment of P8 using BIM is also time-efficient and easily accomplished. The use of Revit in combination with GBS does only require the manual input of the electric cost, the type of PV-panel, the installation cost per m² and the maximum payback period. All other parameters such as the location, orientation or roof-inclination are imported directly from Revit. Only a remark can be made about the fact that GBS only allows to select PV-panels as a renewable energy source. The use of solar panels to produce DHW cannot be explored.

Concerning the energy analysis results, GBS produced similar values to the ones obtained by the REH method for the total primary energy demand (Ntc). Nevertheless, GBS results presented less energy demand for heating (Nic) and more energy demand for cooling (Nvc), when faced with REH results. This fact did not interfere much in in the assessment of P7, which only requires the Ntc value, but it can have significant impact on P8 assessment, which requires Nic and Nvc values. Nerveless, for this case study both methods achieved the same sustainability level for both parameters. The slightly different results in the energy calculations are expected since GBS perform a dynamic simulation and REH method is based on a semi-steady simulation.

Some disadvantages were also noted on GBS: the need to convert GBS results according to SBTool^{PT}-H input units, which required the creation of a conversion spreadsheets. Although the creation of such spreadsheets can take some time, it can also be used in future projects. Nevertheless, GBS cannot be used individually to assess the energy efficiency category of SBTool^{PT}-H, since the reference (conventional practice) values for the energy demand are necessary for the assessment. REH method is always needed to quantify the minimum values (conventional practice) for heating, cooling and total primary energy.

Nevertheless, using BIM to assess buildings energy efficiency allow to speed up the design process and improve project efficiency and sustainability. Designers can select the most cost-efficient way of improving the energy efficiency of their projects without spending too much resources. Implementing BIM to assess buildings energy efficiency can support designers in Portugal (as well as in other countries) to achieve national and EU targets.

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Acknowledgements

The authors would like to thank the support given by BAMB project funded by EU Horizon 2020 under grant agreement No 642384 and to CYTED through URBENERE and CIRES networks. The authors would also like to thank Engineer Ismael Alecrim for the support in the model simulation.