VERIFICATION OF ENERGY DEMAND IN EARLY STAGE DESIGN USING BIM METHODOLOGY

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Abstract
Improving building energy efficiency has become a necessity in construction industry over the last few years. Building Information Modeling (BIM) methodology is a very powerful option to achieve this goal in which the energy demand reduction can be considered in early stage design. Nevertheless, most of building energy simulation software recognized by Spanish government is not integrated in BIM. In consequences, external software is necessary to be used in order to achieve this aim. This process significantly increases the time and computational cost because the interoperability between BIM modelling software and energy analysis software causes several problems during the information exchange.
For the purpose of checking compliance in early stage design, this research has developed a new tool using BIM methodology to check the thermal parameters of vertical building envelope, as set out in the Spanish building regulation. In order to achieve this aim, it has been developed using Python programming language integrated in Dynamo and Autodesk Revit software. This technique provides a set of algorithms of thermal transmittances and compares the results with the established values. All the results are showed in a graphical display and reported as numerical data set schedule. This paper reports the experimental results using a single family detached house in which the parameters of the building envelope are managed in early stage design.

1. Introduction

Currently, building stock is responsible for 36% of European Union (EU) global CO_2 emissions and almost 50% of EU's final energy consumption is used for heating and cooling, of which 80% is used in buildings [1]. Therefore, one of the main goals of Directive 2018/844 is to convert buildings into "nearly Zero-Energy Buildings (nZEBs)" in order to reduce greenhouse gas emissions. Thus, it is important to find a balance between energy consumption and the use of energy from renewable sources with the purpose of reducing the energy dependency and greenhouse gas emissions.
After the 1970s oil crisis, the procedures for the energy simulation systems of buildings started to be created and several software programs have been developed in the last decades using new

technologies for energy analysis [2]. This type of software requires precise information of the model associated with site, geometry and material information and surrounding conditions. A high level of definition of the building seems to be an important task for the energy study.

In many cases, it is necessary to modify the initial parameters of building elements to achieve the energy demand requirements and this information is usually modified many times. This iterative process increases the time and cost of the project because the exchange data information is repeated several times between BIM modelling software and energy simulation platforms.

Nowadays, BIM methodology has been increasingly used in architecture, engineering and construction fields improving the project management [3]. Geometry information, building information and information related to time, costs, sustainability and maintenance can be included in the models based on this methodology [4]. In order to manage information associated with these models, many programs should be integrated in this technology. Industry Foundation Classes (IFC) are an open standard for the interoperability and are used to exchange information between different BIM software, however, this process can provide some loss of semantic meaning for the objects exchanged [5].

Energy performance of buildings integrated in the main BIM modelling software does not provide correct values in accordance with Spanish regulation. Therefore, it is necessary to use energy simulation software recognized by the government to meet the requirement and they are not integrated in BIM methodology. For this reason, there are several researches focused on avoiding the interoperability problems using IFC standards.

This study develops a new tool to check the thermal parameters of vertical building envelope in BIM modelling software based on Spanish building regulation. This system has been developed using Python as the programming language, which provides the significant data set of thermal properties from geometric parameters, building parameters and site of the model.

2. Methodology

This research develops a check tool so as to obtain the thermal values of vertical building envelope adapted to the regulation in BIM modelling software. In this manner, it is possible to manage thermal parameter values from an early stage design. Thermal parameters are calculated using the established criteria in Basic Document Energy Saving (DB HE) in the Spanish Technical Building Code (CTE) [6], although this process could be adapted to other laws with minor modifications.

This tool is integrated in Autodesk Revit modelling software because it has become the most commonly used BIM platform [7] and includes the possibility to develop tools using algorithms in Python as a programming language. Autodesk Revit allows automatically thermal transmittances to be calculated but it is necessary to know how these values are calculated.

In this research, the data obtained in Revit is analysed and compared with the resulting values using the official process defined in Spanish regulation. For this reason, those results provided using both methods of external walls and windows opening have been compared in this work.

2.1. Thermal transmittance of external walls

Thermal transmittances (U-value) of external walls depend on thermal parameters of every layer. U-value is determined by internal surface resistance (R_{si}), external surface resistance (R_{se})

and thermal resistance of each layer (R_t). In each layer, the resistance value (R_t) is associated with layer thicknesses (e) and material conductivities (λ). The calculation is given by the inverse of the total thermal resistance (R) as it can be observed in (1). If the building element is composed by several layers, the thermal resistance (R_t) is given by the sum of the thermal resistances of each layer (i).

$$U\text{-value} = \frac{1}{\left(\sum_{i=1}^{n} Rt_i\right) + Rse + Rsi} \tag{1}$$

Thermal resistance of a layer (i) (Rt_i) is obtained using the thermal conductivity (λ) of the material and layer thicknesses (e) as (2) shown.

$$Rt_i = \frac{e}{\lambda} \tag{2}$$

A priori, Autodesk Revit software automatically obtains the thermal resistance and the thermal transmittance. However, the values calculated in this software are different according to the results following CTE DB HE regulation. This study compares both results in a brick masonry wall made of several layers.

First, the thermal resistance has been calculated in Revit using the default parameters of the software library. On the other hand, regarding the regulation, a new library (HE library) has been developed for the new tool in order to calculate the thermal resistance. In this case, thermal conductivity, specific heat and density of HE library are based on the Spanish technical building catalogue [8].

If thermal resistances are compared, it is possible to observe that these parameters offer different values as shown in Figure 1. The results obtained are 5.2578 m^{2}K/W using Revit default library and 3.3382 m^{2}K/W using the adapted library. These variations are due to the conductivity values of the material and air cavity resistance values. These values are different because the model software calculates these resistances using the cavity thickness and the air conductivity values, while the regulation defines conductivity values for the thickness and ventilation condition of the cavity.
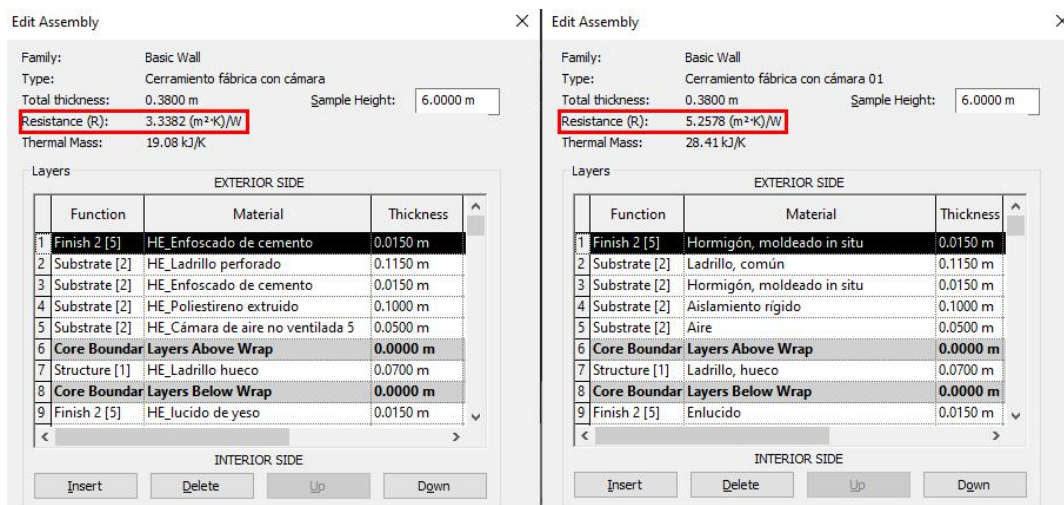

Figure 1: Thermal resistance values with material library adapted (left) and default (right).

Under these circumstances, the thermal transmittances (U-values) obtained are different, because this parameter depends on the thermal resistance, as shown Eq (1). In the case of the value obtained in Revit by default, the result is 0.2996 W/m²K and in the case of the value obtained using HE library, it is 0.2850 W/m²K. This variation is due to resistance values of the layers (R_t) described before, internal surface resistance (R_{si}) and external surface resistance (R_{se}). In the case of R_{si} and $R_{se,}$ they are not considered in the value obtained by default.

Consequently, the new tool based on a set of algorithms performed in Python language in Autodesk Revit obtains the thermal transmittance values for the purpose of checking compliance according to current regulation. Figure 2 describes how to calculate the thermal transmittance (U-value) of walls. This process is repeated several times depending on the number of external walls that the project contains.
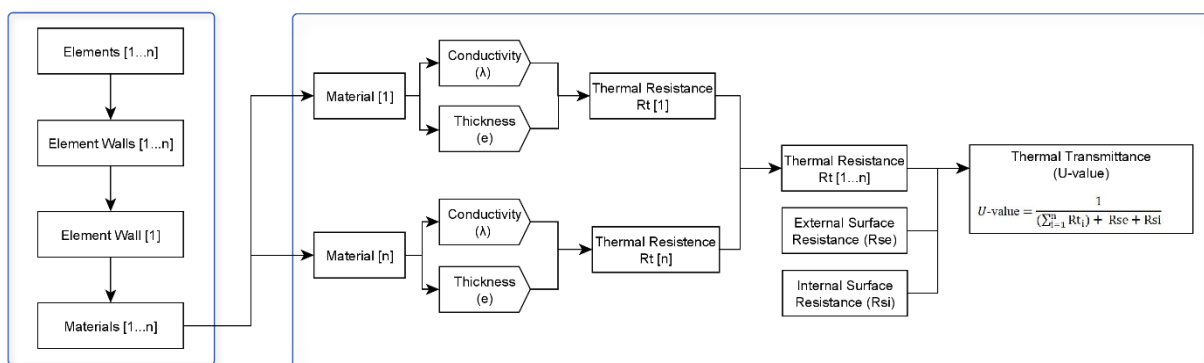

Figure 2: Thermal transmittance (U-value) of walls.

2.2. Thermal transmittance of window openings

For window openings, the calculation is based on thermal transmittance of glazing and thermal transmittance of frame. Basic Document Energy Saving (DB HE) adopts the criteria established in UNE EN ISO 10077 standard in order to obtain this parameter. Global thermal transmittance (U_H) value is determined by thermal transmittance of the glazing ($U_{H,v}$), thermal transmittance of the frame ($U_{H,m}$), glazed area ($A_{H,v}$), frame area fraction (F_M), perimeter length of the glazing (l_v) , perimeter length of opaque panels (l_p) and linear thermal transmittance between elements (Ψ).

Firstly, the thermal transmittance value offered by the modelling software is analysed in this study and it has been verified that the results do not correspond with the established criteria because the thermal transmittance is assigned using its analytical properties, as it can be observed in Figure 3.

Figure 3: Analytical thermal properties options offered by the modelling software.

On the other hand, loadable families of windows have been used for Autodesk Revit which contain additional information related to the thermal transmittance as internal parameter. However, as in the previous case, they are fixed parameters of each window type associated with the window size. This indicates that the parameters associated with each family do not automatically vary when the window size is changed.

In this work, loadable families of windows with thermal parameters have been developed in order to automatically obtain the transmittance values according to the regulation (Figure 4). Particularly, these families are composed of a set of specific parameter: thermal transmittance of frame ($U_{H,m}$), thermal transmittance of glazing ($U_{H,v}$), glazed area ($A_{H,v}$) and frame area fraction (F_M). Linear thermal transmittance between elements (Ψ) is not considered in the value obtained because it presents a very low impact in the results.
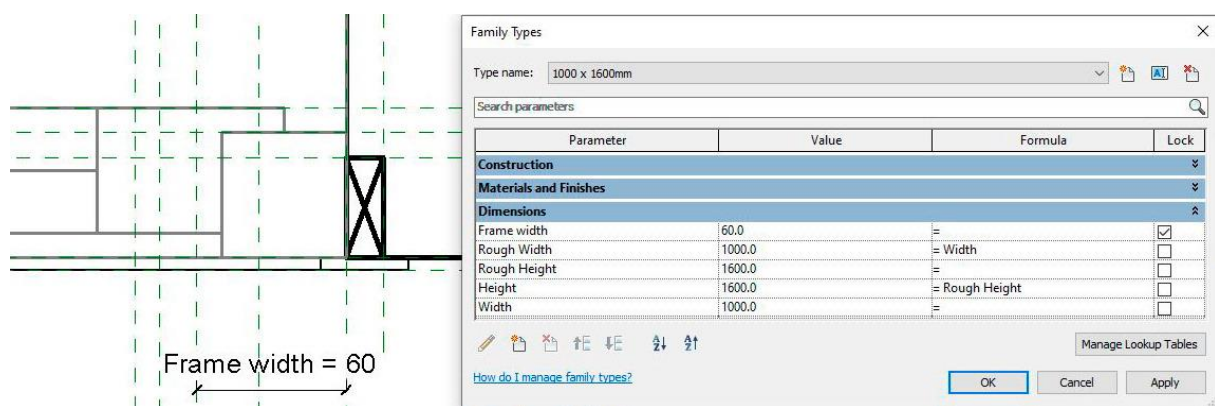

Figure 4: Frame width corresponding to the window family.

The parameters corresponding with transmittance of the glazing ($U_{H,v}$) and transmittance of the frame ($U_{H,m}$) are considered input data for calculations, which are different depending on the window type.

In the case of frame area fraction (F_M), it depends on the width and height of the window and the width of the vertical and horizontal frame profile. This new tool calculates the frame area fraction automatically when the size parameters of the new window family are modified. This process allows different types of windows to be created with different dimensions from the same family, automatically obtaining the frame area fraction.

Once the previous parameters have been obtained, global thermal transmittance (U_H) of windows shall be calculated using equation (3) based on thermal transmittance of the glazing ($U_{H,V}$), thermal transmittance of the frame ($U_{H,M}$), glazed area ($A_{H,v}$) and frame area fraction (F_M).

$$U_H = \frac{\left(A_{H,V} * U_{H,V}\right) + \left(F_M * U_{H,M}\right)}{A_{H,V} + F_M} \tag{3}$$

In order to automate this process, it has developed a set of algorithms using Python programming language in the modelling software as shown in Figure 5. This process is repeated a certain number of times depending on the number of elements.
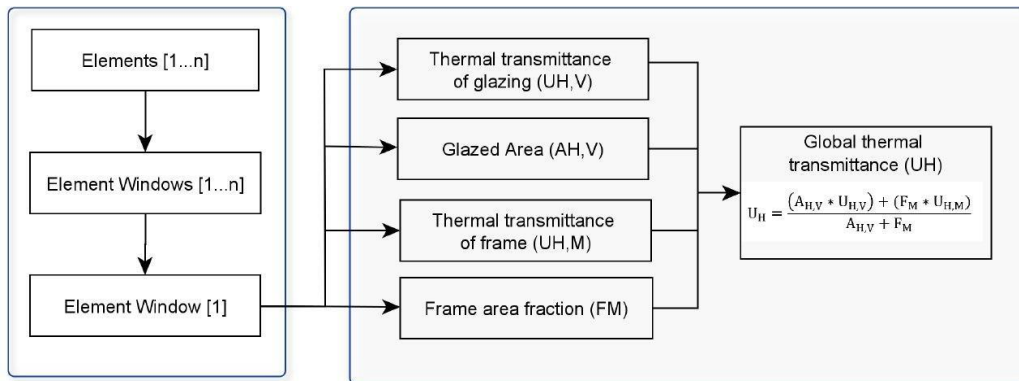
Figure 5: Global thermal transmittance (UH) of windows.

3. Experimental Results

In this section, the experimental results are reported using a one-storey single family detached house composed of two twin volumes with different heights made of brick masonry walls, insulation and cavity. Window openings are made of aluminium frame and double glazing with internal air gaps.

Once the building geometric of the model has been created and the project location has been defined, the elements of thermal envelope have been established using the specific materials of HE library and new families of windows as shown in Figure 6. In consequence, the thermal transmittance results of vertical envelope are obtained in accordance with the new tool.
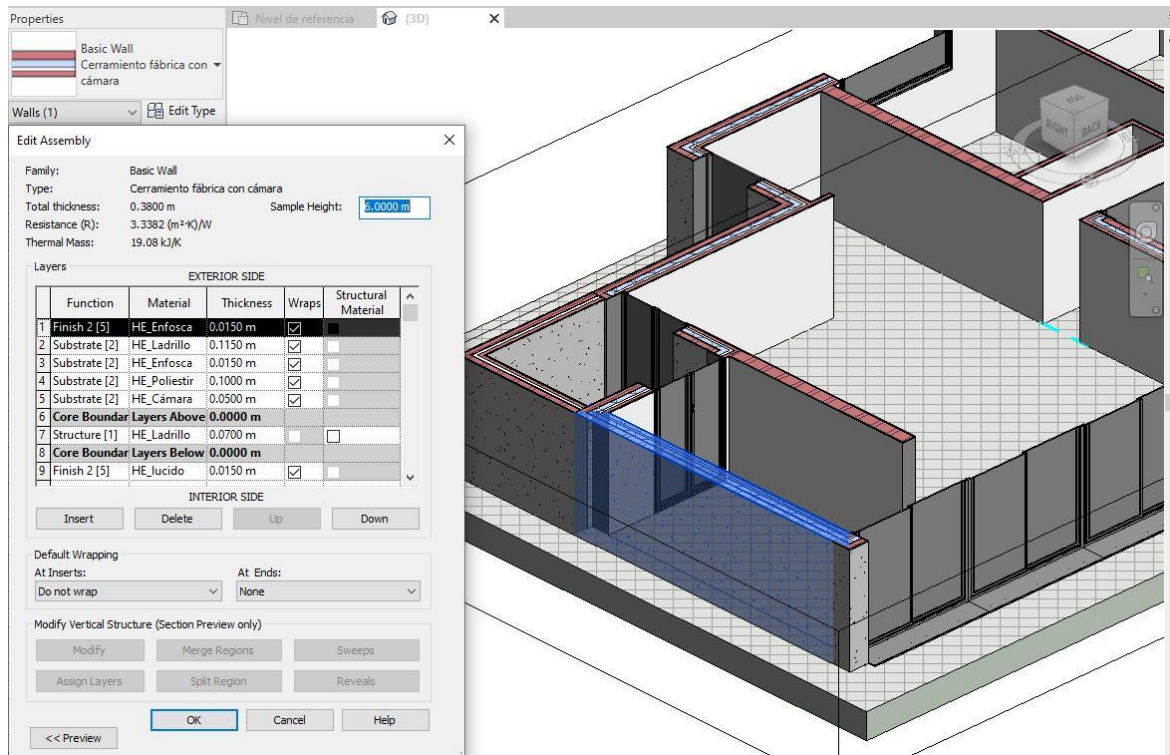

Figure 6: Wall definition using HE material library.

In order to show the thermal transmittance results of walls in more detail, Figure 7 shows the family walls and the function (interior or exterior), the thermal resistance (R) and the thermal transmittance (U-value) of each wall. In addition, this figure includes information about the orientation because this parameter is needed to select the reference thermal transmittance values.

<Wall thermal transmittance>					IMex
A	**B**	**C**	**D**	**E**	**F**
Family and type	Function	Thermal envelope	Orientation	Thermal resistance (R)	CTE Transmittance
Ground level					
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	NE	3.3382 (m²·K)/W	0.285
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	SE	3.3382 (m²·K)/W	0.285
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	SW	3.3382 (m²·K)/W	0.285
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	NW	3.3382 (m²·K)/W	0.285
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	SW	3.3382 (m²·K)/W	0.285
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	NW	3.3382 (m²·K)/W	0.285
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	SW	3.3382 (m²·K)/W	0.285
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	NW	3.3382 (m²·K)/W	0.285
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	NE	3.3382 (m²·K)/W	0.285
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	SE	3.3382 (m²·K)/W	0.285
First level					
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	NE	3.3382 (m²·K)/W	0.285
Basic Wall: Cerramiento fábrica con cámara	Exterior	☑	NW	3.3382 (m²·K)/W	0.285

Figure 7: Experimental results of external walls.

In the case of windows, the experimental results obtained are illustrated in Figure 8 which shows the information of the window type, the exterior window blind, the thermal transmittance of the frame ($U_{H,M}$), the thermal transmittance of the glazing ($U_{H,v}$) and the global thermal transmittance (U_H).

<Window openings transmittance>						IMex
A	**B**	**C**	**D**	**E**	**F**	**G**
Type	Model	Thermal envelope	Blind	Frame transmittance	Glazing transmittance	Global transmittance
Ground level						
Ventana abatible 2 hojas: 1500 x 3150mm	V03	☑	☐	1.4	5.7	5.012
Ventana abatible 2 hojas: 1500 x 3150mm	V03	☑	☐	1.4	5.7	5.012
Ventana corredera 2 hojas: 2500 x 3150mm	V01	☑	☐	1.7	2.1	2.073
Ventana corredera 2 hojas: 2500 x 3150mm	V01	☑	☐	1.7	2.1	2.073
Ventana corredera 2 hojas: 2500 x 3150mm	V01	☑	☐	1.7	2.1	2.073
Ventana corredera 2 hojas: 2500 x 3150mm	V01	☑	☐	1.7	2.1	2.073
Ventana corredera 2 hojas: 3150 x 2500mm	V02	☑	☐	5.7	4.5	4.585
Ventana corredera 2 hojas: 3150 x 2500mm	V02	☑	☐	5.7	4.5	4.585
Ventana corredera 2 hojas: 3150 x 2500mm	V02	☑	☐	5.7	4.5	4.585
Ventana corredera 2 hojas: 3150 x 2500mm	V02	☑	☐	5.7	4.5	4.585
Ventana proyectable 1 hoja: 1250 x 800mm	V05	☑	☐	1.2	2.8	2.429
Ventana proyectable 1 hoja: 2400 x 800mm	V04	☑	☐	1.2	2.8	2.492
Ventana proyectable 1 hoja: 2400 x 800mm	V04	☑	☐	1.2	2.8	2.492
Ventana proyectable 1 hoja: 2400 x 800mm	V04	☑	☐	1.2	2.8	2.492

Figure 8: Experimental results of window openings.

Once thermal transmittances have been calculated, the results obtained are compared with the reference values set out in Spanish regulation. For illustrative purposes, a colour code has been applied to the model in order to identify which elements meet the requirements. The elements that meet the requirements can be seem in green colour while the elements shown in orange do not meet them. This method helps to easily identify the results in 3D dimensional model as Figure 9 shown.
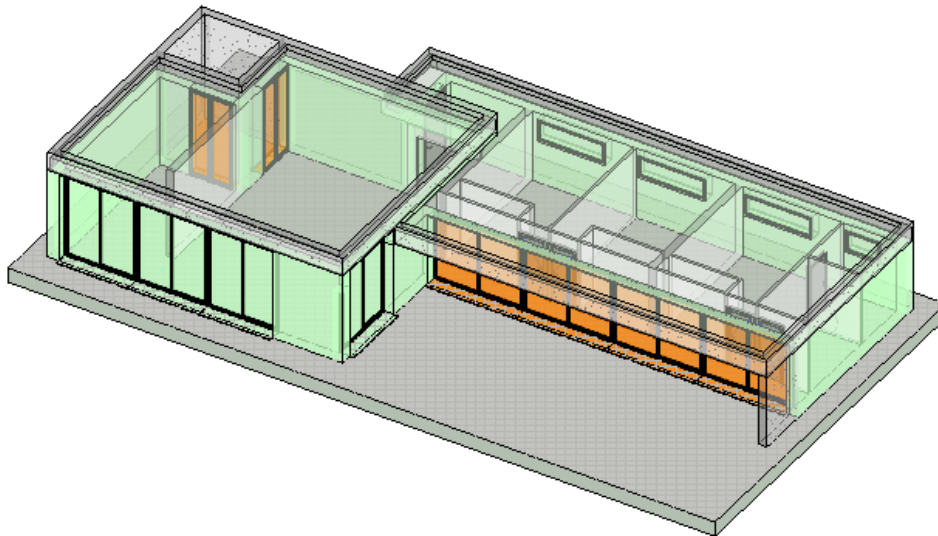
Figure 9: Graphic results of the proposed methodology.

Therefore, the developed tool calculates the thermal parameter of building envelope and compares these results according to the reference values of the Spanish building regulation integrated in the modelling software. One of the main advantages is the possibility to modify the building elements and their parameters in the early design stages. Consequently, an optimized building model can be obtained before the information exchange between the modelling software and energy simulation software takes place.

4. Conclusions and future research lines

This research develops a new tool integrated in BIM methodology in order to obtain adapted models based on energy saving regulations in an early stage design. To achieve this purpose, loadable windows families have been created as well as HE materials library and a set of algorithms using Python programming language integrated in Autodesk Revit.

The process provides automatically thermal transmittance results of vertical building envelope and compares them with the limited values established in Spanish regulation. The tool reports the results in numerical data set schedule and graphical display of 3D model. Computational cost and time are reduced significantly in the project because information exchange between BIM platforms and energy simulation software is minimized.

A future work, the tool will be extended with elements of the horizontal thermal envelope. In this sense, it will allow all the parameters to be managed in the whole thermal envelope.

5. Acknowledgment

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