Parameterization applied to building energy performance

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ABSTRACT
The parameterization of energy efficiency measures is used in thermal and energy simulation processes in which gradual evaluations through simulation aim to obtain solutions for the building design. The procedures were improved through the decades towards the optimization of solutions, which optimized parameters have interrelated impacts on the building performance. Optimization methods involve complex sensitivity analysis, which adopts complex methods as Latin Hipercube for sampling or Neural Networks for evaluations, but also simplified analysis using linear regression equations. The Brazilian Labeling Program of Inmetro uses regression parametric equations of to identify the energy efficiency level of housing units. This study investigates shape parameters of a housing model using those regression algorithms. The variation of two shape parameters (width and depth of interior rooms), affected several labeling parameters, which results indicate the direction to introduce a shape grammar for energy efficiency of dwellings.

KEYWORDS
parametrization, energy efficiency, sensivity analysis, residential labeling.

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1. INTRODUCTION

The parameters applied to studies of energy efficiency in buildings began with the analysis of building systems and construction materials. The goal was to reduce the building energy consumption (Cordoba, Macias and Espinosa, 1998) in an analysis involving costs from installation of energy efficiency measures and energy savings (Rosenfeld, 1996). As the computing resources enhanced in processing capacity and graphical interfaces, evaluations using simulations of the energy performance now include parameters that visually affect the shape of the building and the facade. As an example, solar protections *brise soleil* with complex geometries affect performance by integrating energy savings of air conditioning by shading and saving energy of artificial lighting, by the use of daylight (Carlo, Pereira and Lamberts, 2004). The mentioned economies are conflicting, and the solutions obtained with the parametric simulation aimed at finding the optimal shape between two goals that have inverse results for the same solution. Such analyses tend to be focused on one or two specific issues to be incorporated in the design and evaluated globally.

Araújo, Pedrini and Tinôco (2008) described the process of energy simulation-based design. From an initial proposal of the building obtained from volumetric studies, the specific problems of each party - such as ventilation courts due to porosity or shading of the façades - were simulated and evaluated separately and incorporated into the design, each in its own time. It is worth noting that while energy efficiency measures have been assessed at different times, they have not been evaluated individually: the whole building was simulated so that the impacts of this solution were recorded in the following analysis. We see, therefore, a linear development of a proposal to incorporate gradually the energy efficiency design solutions in a traditional process of architectural creation. Considering that, the parametric simulation is a process to assist the solution of problems which provides data for the architect to review the performance and create the most appropriate solutions to the case.

Other methods for making decisions involved cases of process of optimization in order to analyze the interaction between parameters and their impact on building performance. The solutions were evaluated linearly: at each step, a number of problems was investigated. As one solution affects the performance of the other, parameterization implied in: evaluation all the solutions separately; identifying those with the greatest impact; incorporating them into the base model to finally evaluate the performance of other parameters in this new base case and, thus, repeat the process (Martinaitis et al., 2004)

This is what Carlo (2008) showed in the simulations to optimize the performance of commercial facades of buildings. She used parameters which describe the relationship of Window to Wall Ratio, glazing and the shape of solar protections in order to find the best solution that integrates the costs from energy savings to the investment of the installation of the measure still in the design phase. Therefore, she adopted a linear optimization process with parametric analysis, where all parameters were simulated individually, the greatest impact was identified and incorporated so that the other parameters were evaluated in the following round of simulations. These parameters were then used to create numerical models for multivariate linear regression describing the effects of the facade on the building performance (Brazil, 2010).

In the 2010s, the modeling and simulation capabilities became more advanced, as well as the processes of interaction of the parameters regarding to the energy performance. The evaluations began to incorporate a higher number of interdependent parameters and broadened the scope of interactions to thousands of cases (Eisenhower et al., 2012). In Brazil, the metamodels created by the Energy Efficiency in Buildings Laboratory in 2014, whose research uses dozens of slave computers of the institution to process 1 million parametric simulations using EnergyPlus (Lamberts, 2014) is awaiting publication. Statistical processes began to be adopted in the pursuit of the optimal solution from other mathematical methods other than regression, which would increase the range and reliability of the studied cases (Melo et al., 2013).

In section 2, some of the approaches widespread in 2010s are presented to support the analysis presented in this article about the dwelling shape focused on the criteria of the energy efficiency labeling program.

In general, energy efficiency studies deal with parameters related to systems such as automation, lighting and air conditioning (Rosenfeld, 1996; Martinaitis, 2004), or with parameters related to the building materials (Silva and Ghisi, 2014; Sorgato et al., 2014). The architectural shape is rarely evaluated in terms of performance. The shape was investigated by Carlo and Lamberts (2007), where building volume indicators were parameterized but, realizing that the performance is not linear at volumes, Carlo (2008) created more than one regression equation for the PBE Edifica of the commercial sector (Brazil, 2010) depending on the size of the building. In a similar approach, Versage (2009) and Sorgato (2009) analyzed types of high-rise and single-family buildings to, finally, develop regression equations for the residential labeling program to analyze each room separately (Brazil, 2012). Thus, this work investigates the differences on the energy performance according to the PBE Edifica of the residential sector (Brazil, 2012) due to the variation of two parameters of shape of rooms, depth and width, which generate impact in several performance parameters of a dwelling, as well the impact on its final shape. After presenting the statistical methods adopted in the area in the years 2010, the work focused on a regression equation for parametric analysis of the residential labeling, where its relevance and its use are shown.

2. ANALYSIS METHODS FOR ENERGY PARAMETERS IN BUILDINGS

2.1. Sensitivity analysis

According to Tian (2013), sensitivity analysis are statistical tools with potential to be used in studies of parameters involved in the energy performance of buildings. It assists the decision-making from the understanding of the influence of these parameters in identifying what may be simplified and what should be more robust, in quantifying the confidence level of a model and in optimizing input data (Hopfe and Hensen, 2011).

Techniques for application of sensitivity analyses can be divided into three different categories: screening, local and global. Analysis by screening may be useful for preliminary investigation or trial, but they are inaccurate. The basic concept of screening techniques is the test of the two extreme values, maximum and data, minimum, of input while the others are kept as average values (Silva and Ghisi, 2013). Otherwise, analysis known as local has, as a basic concept, a wider variation range of a particular input data, but it maintains the other parameters as constants. As an advantage, it requires low time and computational costs, but it does not consider the interaction between the parameters (Silva and Ghisi, 2013; Tian, 2013). Finally, the global sensitivity analysis involves a high time and computational cost, but it allows the variation of parameters all together, as well as the analysis of a full variation range of the parameter. This method is more accurate and comprehensive and, moreover, it allows the quantification of global sensitivity indexes (Silva and Ghisi, 2013; Tian, 2013). These analyses deal with previous records or databases and enable to assess results with a minimum of uncertainty in comparison to a real building (Melo et al., 2012). Depending on the complexity of the case and the time available to conduct the analysis, gathering the complete record can cover the entire universe of possibilities. In the case of a large number of data, there is a need to select a sample representing this universe.

2.2. Sampling

In cases which there is a need for sample selection, it is important to ensure that the sample used for the study can represent and perform the used statistical method, considering that a sample with low quality may induce to errors in the interpretation and, therefore, in decision-making. Thus, there are appropriate techniques for each type of situation (Melo et al., 2012). The most frequently used parametric sensitivity analysis are the "Not Random", which consists in the variation of a single parameter in each new selected case, and it is varied in a controlled manner (Tian, 2013). This technique allows an evaluation of the influence of each

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single parameter on the dependent variable, although it does not allow an evaluation of the influence of the interaction of two parameters on the results (Melo et al., 2012). The most qualified methods refer to global analysis, which deals with stratified and random sampling, by linking the process to certain probability or uncertainty distributions whose are defined according to each input variable (Tian, 2013). The Latin Hypercube method is distinguished among the others by using the distribution ranges rigorously elaborated. One of its advantages is the high reliability with the use of fewer samples, though it maintains a coverage of all the sample boundaries (Melo et al., 2012). As an example, the probability of glazing area is triangular (Figure 1) while the ceiling heights of residential rooms is uniform (Figure 2).

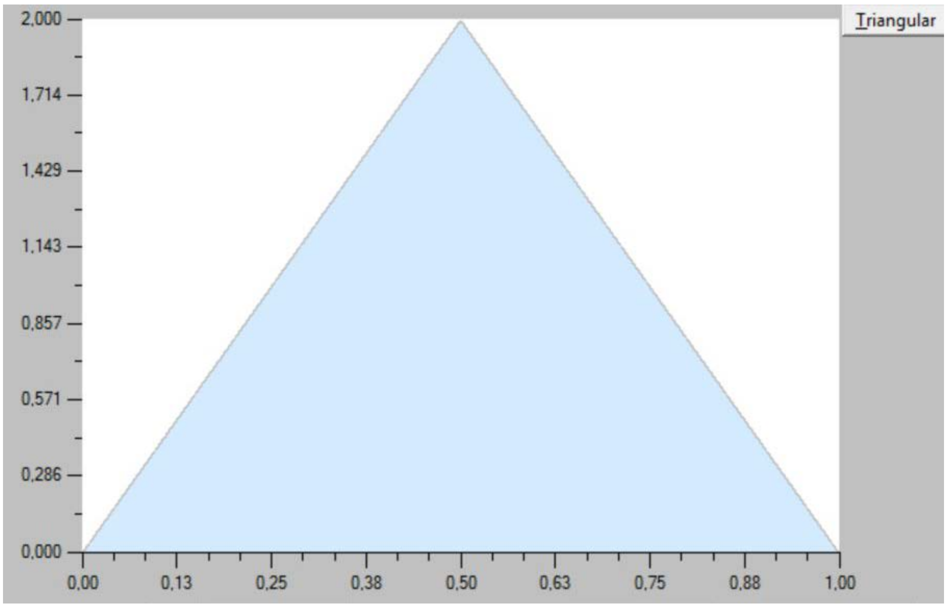

Figure 1. Triangular distribution probability of the occurrence of glazing area in façades of commercial buildings, obtained with the software SimLab. Source: authors.

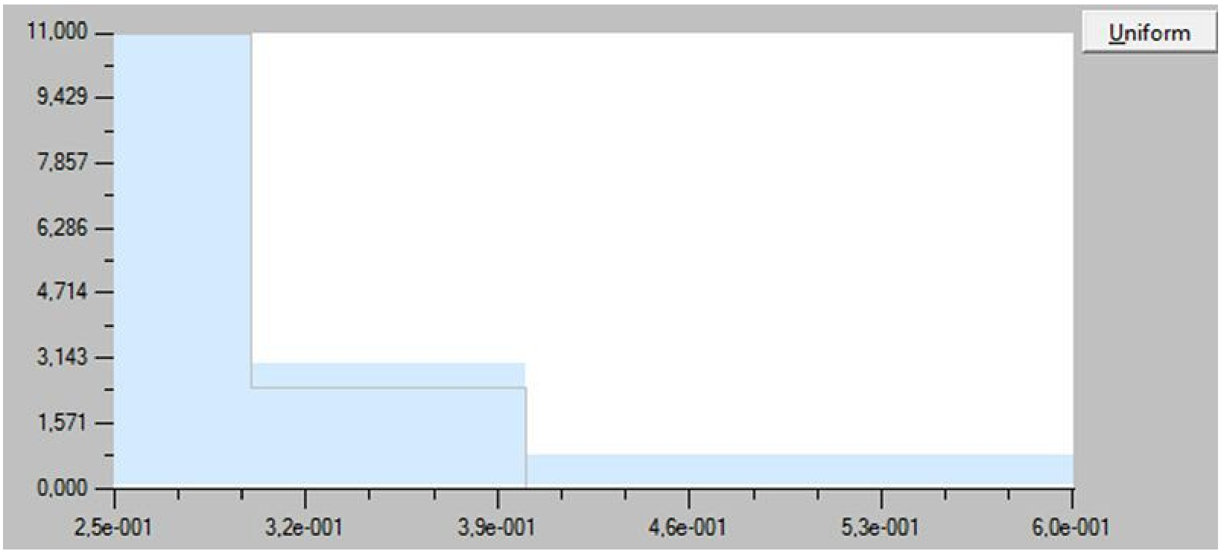

Figure 2. Uniform probability distribution of the occurrence of the ceiling heights of residential rooms, obtained with the software SimLab. Source: authors.

2.3. Neural networks

Artificial neural networks (ANN) is a global sensitivity analysis method that is capable of performing learning based on pattern recognition through algorithms inspired in the animal neuron network.

ANN is usually presented as artificial neurons interconnected systems, which can estimate values for inputs and transmit the output values among themselves, and the connections programmed between neurons determines when and how much a node influences another node. Neural networks still have the ability to learn, as a brain, through examples and use the findings from this training to improve the performance of their tasks.

The advantages of using ANN as sensitivity analysis method are: it has the lowest rate of uncertainties in forecasts obtained; it provides quick answers; it allows an exemption from linearity between the input and output variables, such as some regression models, and are user friendly after its reliability is established.

2.4. Optimization

All the issues previously addressed tend to feed the optimization process in a design. The Parametric Simulation Method can be the basis for sensitivity analyses or neural networks, both created using different sampling methods or previous records, as well as the own simulations, to solve problems regarding to the performance of a building.

They are iterative methods, which carry out progressive improvements in the model until the convergence to a "solution", which means a point in the search range that satisfies a condition of optimization created by parameters that may be variables while others are constant. The Parametric Simulation Method feeds the Optimization Based Simulation (OBS) (Nguyen et al., 2014), whose ultimate goal is to find the best solution for the design.

The steps of OBS were defined by Nguyen et al. (2014) as pre-processing, optimization of execution and post-processing, which involve the formulation of the problem, the control of the process completion criteria and the interpretation of results, respectively.

3. Regression Models Of PBE Edifica

The processes mentioned above deal with a number of parameters that can generate thousands of cases, each with its methods of analysis. They consist in the foundation of the research of parameterization on energy efficiency that should generate products for simplified parametric analyses, which, on its turn, are usually based on statistical data regarding the building stock market.

In Brazil, the simplified analyses emerged from multivariate regression of energy performance parameters of buildings. They are presented in the regulations of the Brazilian Labeling Program of Inmetro, which quantifies the level of energy efficiency of equipment and of buildings; the latter, since 2009 (Figure 3). The regression equations indicate the levels of energy efficiency with the use of an alphanumeric scoring (Table 1) (Brazil, 2010, 2012).

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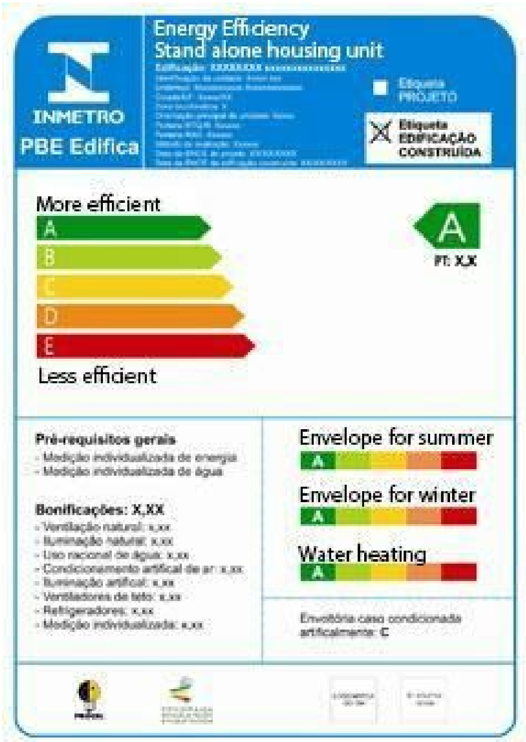

Figure 3. The National Label of Energy Conservation for housing units, which prescriptive method was established though parametric analysis, indicates the energy efficiency level of a house or an apartment. Source: Adjusted from Brazil, 2013 [authors translation].

Score	Energy Efficiency Level
≥4,5 a 5 A	A
≥3,5 a <4,5 B	B
≥2,5 a <3,5 C	C
≥1,5 a <2,5 D	D
<1,5 E	E

Board 1. Scores for the energy efficiency levels of a HU. Source: Brazil, 2012 [authors translation].

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Such equations allow decisions-making which impact materials, ventilation systems, the facade composition and shape of the building.
This work aims to analyze the influence of shape parameters of housing units in the energy efficiency level of the envelope using the prescriptive method of PBE Edifica of the residential sector, using two parametric regression equations. The evaluated parameters were depth and width of extended permanence rooms. Considering a housing unit with 4 rooms, there were 8 parameters for single variation. On its turn, each of these 8 parameters impacted directly 10 parameters and, indirectly, other eight parameters of the equation.

4. METHOD

The parametric analysis method was developed with three models: two numerical models for energy analysis applied to a graphical model representing a housing unit. The evaluated parameters are the shape of the rooms of a housing unit (HU), that impact the parameters of the numerical models.

4.1. Numerical models for the evaluation of the energy efficiency label

The numerical models contain two linear regression equations that were generated by parametric simulation for the PBE Edifica of the residential sector: one to characterize the performance of HU for the summer (Equation 1) and one for the winter. The performance equation for the winter has a similar structure to the one for the summer, with the same parameters.

The equations were used to assess the level of energy efficiency of housing units with different volumetric provisions of housing unit (HU), according to the prescriptive method of RTQ-R (Brazil, 2012) for Bioclimatic Zone 3[1] (ABNT, 2005).

$$CDH = (836.4188) + (1002.2853\ CTlow) + (1248.7615\ \alpha roof) + (-1042.8507\ shad) + (-7.9675\ ground\ AUroom) + (1007.6786\ \alpha wall) + (2324.8467\ CH/AUroom) + (-0.3032\ CTroof) + (-77.7838\ AbS) + (26.3363\ AProomE\ Uwall\ \alpha wall) + (-0.0016\ AwallInt\ CTwall) + (-605.5557\ ground) + (25.1879\ Uroof\ \alpha roof\ roof\ AUroom) + (-830.6742\ Fvent) + (34.1620\ AUroom) + (-3.3292\ SumAwall) + (16.9856\ AAbO\ (1-shad)) + (70.1758\ AAbE\ Fvent) + (-0.0426\ CTwall) + (-54.1796\ AAbS\ (1-somb)) + (14.1195\ AProomN\ Uwall\ \alpha wall) + (-114.4985\ sti) + (399.0021\ ProomW) + (2.4466\ AAbN\ shad) + (-379.5777\ AbN) + (738.1763\ ProomN) + (-4.2304\ AProomN) + [5.5988\ (Uroof\ \alpha roof/CTroof)\ AUroom] + (-6.1829\ roof\ AUroom) + (-200.9447\ CThigh) + (-103.1092\ Uroof) + (3.8400\ AProomS\ Uwall\ \alpha wall) + (3.8400\ ProomE) + (16.2740\ AwallInt) + (-20.4181\ CH\ AUroom) + (126.6339\ ProomS) + (51.1530\ AAbS\ Fvent) + (55.4249\ AAbW\ Fvent) + (79.2095\ AAbN\ Fvent) + (15.3351\ AProomW\ Uwall\ \alpha wall) + (26.0925\ AProomS) + (-34.7777\ AAbN\ (1-shad)) \quad \text{Equation 1}$$

[1] Bioclimatic analyses in architecture use to adopt NBR 15220 (ABNT, 2005) parameters which separates the Brazilian territory in 8 bioclimatic zones, that are homogeneous geographical regions "regarding the climatic elements which interfere in the relationships between the built environment and human comfort" [authors translation].

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Meaning,

Parameters of the building shape:

$Ab_{E,N,W,S}$: indicates the existence of openings facing one of the 4 cardinal directions;

$AAb_{E,N,W,S}$ (m^2): openings area, facing one of the 4 cardinal directions;

$APamb_{E,N,W,S}$ (m^2): area of exterior walls, facing one of the 4 cardinal directions;

AwallInt (m^2): area of interior walls;

AUroom (m^2): floor area of the analyzed room;

Chigh: rate between room high and floor area;

CH (m): ceiling height;

$Proom_{E,N,W,S}$ (m^2): indicates the existence of exterior wall facing one of the 4 cardinal directions;

SumAwall: sum of the área of all exterior wall of the analyzed room;

volume (m^3): room air volume.

Parameters of materials thermal properties:

CThigh[kJ/(m^2K)]: defines if the opaque shell of the rooms have high thermal capacity;

CTlow[kJ/(m^2K)]: defines if the opaque shell of the rooms have low thermal capacity;

CTroof [kJ/(m^2K)]: thermal capacity of the roof;

CTwall [kJ/(m^2K)]: thermal capacity of exterior and interior walls;

Uroof [W/(m^2K)]: thermal transmitance of the roof;

Uwall [W/(m^2K)]: thermal transmitance of exterior walls;

Uglaz [W/(m^2K)]: thermal transmitance of glazing;

αroof (adimensional): solar absorbtance of the roof;

αwall (adimensional): solar absorbtance of the exterior walls.

Other parameters:

Fvent (adimensional): rate between ventilation opening area and full opening area;

cob: defines if the room has opaque shell in contact with the exterior environment (roof);

isol: defines the existence of insulation on walls and roof;

sti: defines if the room presents floor in contact with the exterior environment (stilt);

ground: defines if the room presents floor in contact with the ground;

shade: defines the existence of solar protections;

vid: indicates the existence of double glazing fenestration.

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As it was seen, the Equation 1 presents several parameters. Those with higher relevance to the parametric evaluation were mentioned. However, this discussion requires a previous presentation of the HU model.

4.2 Housing Unit model

The stand-alone housing unit (HU) was based on the prototype set by Tavares (2006) for average income. The used equation refers to the Bioclimatic Zone 3 (ZB3), which incorporates climates with constructive needs common to the cities of Sao Paulo, Florianopolis, Porto Alegre, Belo Horizonte and Viçosa - MG. Although some restrictions have been included by the municipality of the Viçosa Construction Code - MG, the rest may be valid for other mentioned cities.

The HU consists of a ground floor which contans: living room, two bedrooms, office, bathroom, kitchen and hallway. The base plant is shown in Figure 4.

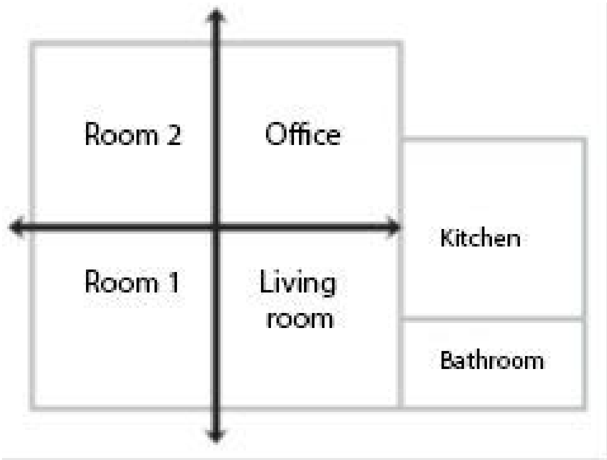

Figure 4. Base plan of the studied object. Source: authors.

This is a standard model commonly found on households, whose characteristics are sufficient to describe the energy parameters inherent to the shape: the surface areas exposed to the exterior and the adjacent interior rooms, as well as the openings (doors and windows). Such relationships also depend on the materials constituting the shells, as well as the interior rooms conditions (hours of occupancy, number of people, metabolism and equipment) that can generate heat and can modify heat transfer to adjacent rooms. The internal use conditions and building materials were maintained constant to change the shape and consequently their relationships with outdoor accordance with the ZB3 efficiency levels.

4.3 Parameters of the models

The variables and constant parameters are discussed according to the restrictions in RTQ-R regulations (Brazil, 2012).

4.3.1. Constants

The parameters that are the pre-requisite of RTQ-R were considered as restrictions to the model. The failure to comply with pre-requisite implies an efficiency level of the envelope for summer conditions in up to level C.

- **Openings**

Extended permanence rooms must have minimum percentage of ventilation openings area of 8% for ZB3. In the proposed model, the cardinal direction of openings was fixed, whose area is 17% of the floor area of the room to meet both the minimum of Viçosa Municipality Building

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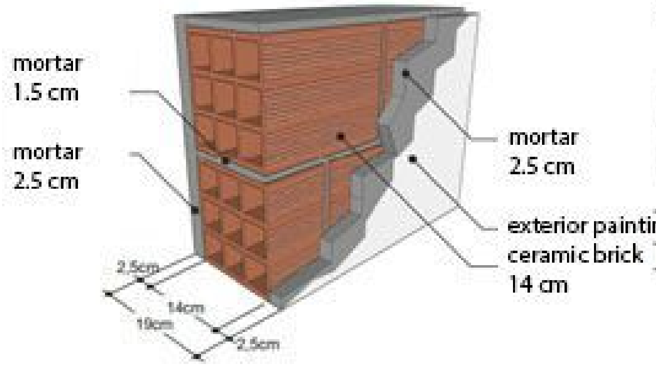
Code - MG (Viçosa, 2004) and the RTQ-R (Brazil, 2012). This percentage also attended the daylight prerequisite, whose lower limit was 12.5%. Furthermore, shade = 0.2 was maintained constant due to the eaves on the HU.
The HU cross ventilation also met the prerequisite that requires an external and internal openings system to promote the air flow through, at least, two different façades.

- **Rooms dimensions**

The areas of short permanence rooms of the HU were kept constant, as their performance is not included in the labeling, though additional requirements affect the efficiency level of envelope. As kitchen and bathroom fall into this category, according to RTQ-R (Brazil, 2012), the dimensions were kept 3.0m x3.5m for the kitchen and 3.0m x 1.5m for the bathroom. Other parameters were: ceiling height of 3m, exterior door of the HU and all rooms positioned in contact with the ground.

- **Materials**

There are prerequisites for the thermal properties of materials and components of walls and roofs of the HU. Typical materials of Brazilian constructive culture were selected (Figures 5 and 6) among those who met the prerequisites for level A of Table 1. Selected solar absorbtance, 0.2 for walls and 0.4 for roofs, are corresponding to white color and ceramic.

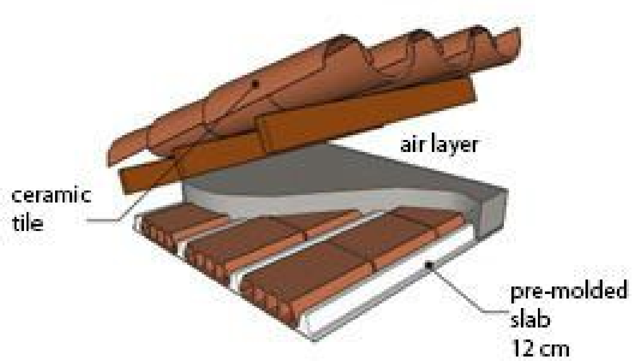


Description

Mortar (2.5 cm)
Ceramic brick (14.0 x 19.0 x 29.0) cm
Mortar (2.5 cm)
Exterior painting

U [W/(m²K)]	C_T [kJ/m²K]	α [-]	FCS [-]
1,85	161	0,2	1,5
		0,4	3,3
		0,8	5,9

Figure 5. Wall materials and its thermal properties. Source: adjusted from LabEEE, 2011 [authors translation].



Description:

Pre-molded slab 12 cm (concreto 4 cm + ceramic brick 7 cm + mortar 1 cm)
Air layer (> 5.0 cm)
Ceramic tile

U [W/(m²K)]	C_T [kJ/m²K]	α [-]	FCS [-]
1,79	185	0,2	1,4
		0,4	2,9
		0,8	5,7

Figure 6. Roof materials and its thermal properties. Source: adjusted from LabEEE, 2011 [authors translation].

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Bioclimatic zone	Component	Solar absorbtance (adimensional)	Thermal Transmitance [W/(m²K)]	Thermal Capacity [kJ/(m²K)]
ZB3 to ZB6	Wall	α ≤ 0,6	U ≤ 3,70	CT ≥ 130
		α > 0,6	U ≤ 2,50	CT ≥ 130
	Roof	α ≤ 0,6	U ≤ 2,30	-
		α > 0,6	U ≤ 1,50	-

Table 1. Wall and roof pre-requisite for levels A and B of efficiency. Source: adjusted from Brazil, 2012.

4.3.2. Variables

- **Room dimensions**

The evaluated parameters were those related to the shape of extended permanence rooms [2] (EPR). It is noteworthy that the Viçosa Building Code imposes the minimum areas of residential buildings partitions according to the destination or activity: 6.00 m^2 for the sleeping or resting; 9.00 m^2 for the being ou leisure; 4.00 m^2 for food preparation.

Two parameters of shape were used - dimensions in plan view in two orthogonal axes - which imply amendments in several variables of the equation for the evaluation of energy efficiency. Such parameters do not alter the space syntax of the HU, whose origin is fixed at two axes whereby the four extended permanence room are located, as illustrated in Figure 7.

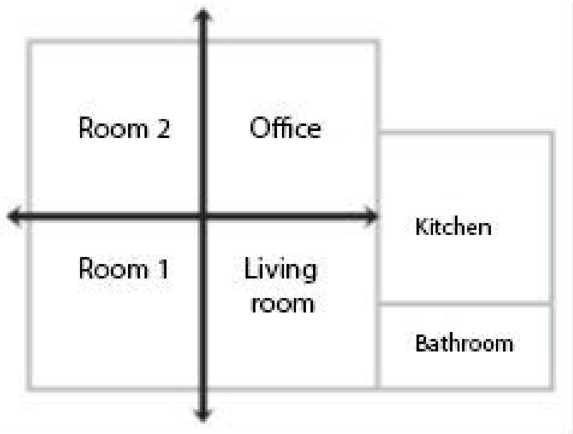

Figure 7. Plant of the standard design with the axes of dimensions expansions. Source: authors.

Then, it was determined how such parameters would relate to the plant of the HU. A first event, represented by Figure 8, was performed in which an arbitrary fixed north perpendicular to one of the cardinal axes for the purpose of simplifying calculations, and varying the dimensions of APPs along the axis of expansion of the form.

[2] According to RTQ-R (BRAZIL, 2012), EPR are the rooms whose present extended occupancy by one or more people, as living room, dining room, bedroom, home office or TV room.

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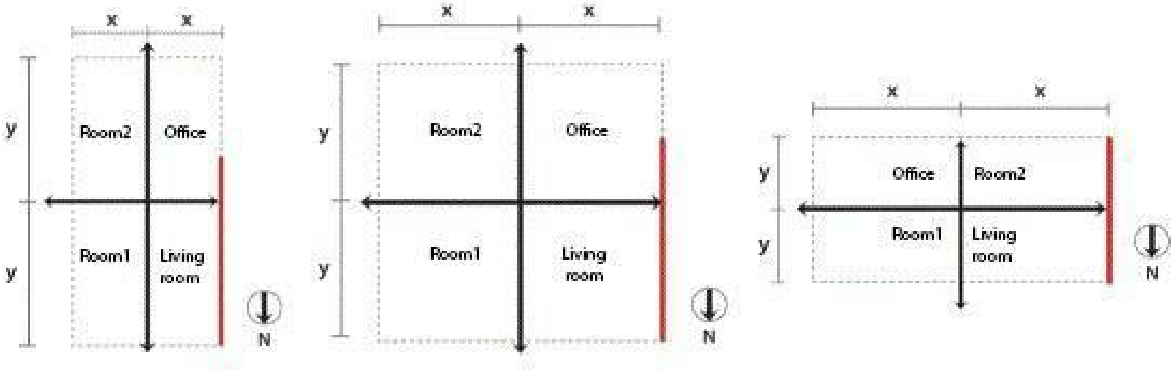

Figure 8. Expansion possibilities of rooms dimensions, which red line indicates the contact surface with the bathroom and the kitchen. Source: authors.

It can be observed that in situations where the proportions of X and Y are increased or decreased, a resultant stretched shape was created in one of the axis. Considering that, it is preferred to work with a better process to balance the two variables spatially. It was then determined the final disposition shown in Figure 9. To simplify the automation of data and to meet geometric requirements of the plant, restrictions were established for x and y values: $x \geq y$; $x \geq 2.5$ and $y \geq 1$**.**

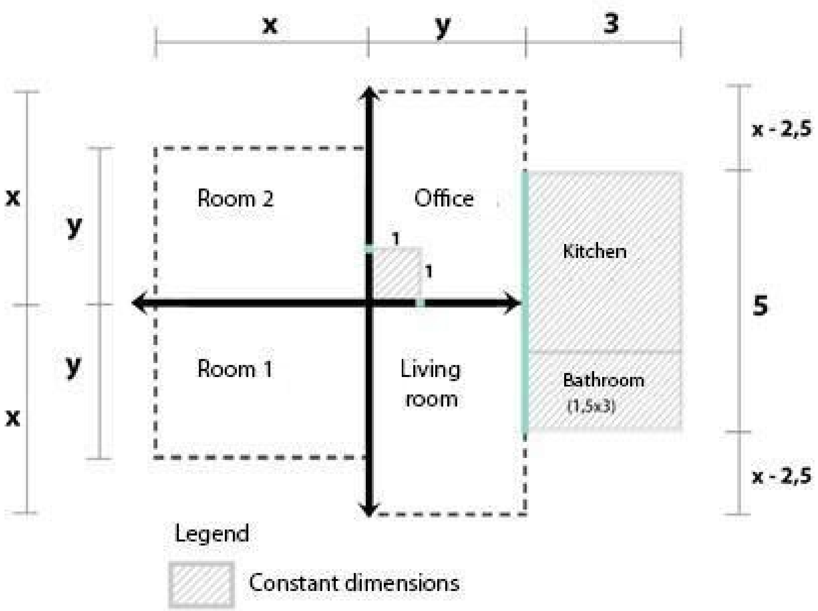

Figure 9. Definition of the variables position. Source: authors.

The Viçosa Building Code requires that, regarding extended permanence rooms for sleeping or resting, the smaller accepted area is 6 m². Then, the following values were determined as minimum dimensions: $x \geq 2.5$ m and $y \geq 2.5$ m. The maximum dimensions were based in the living room + dining room for average income pre-established by Tavares (2006): $x \leq 6.1$m

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and y ≤ 6.1m. Ten intervals were created between the highest and the lowest value, which results in a total of 55 housing units.

5. RESULTS AND DISCUSSION

Figure 10 represents proportionally the result of the shape projection (in plan view) of extended permanence room of the HU - note that short permanence room were excluded from the image – according to the crossing values of x and y dimensions, generating different floor areas and different exposure areas of the building to the exterior environment.

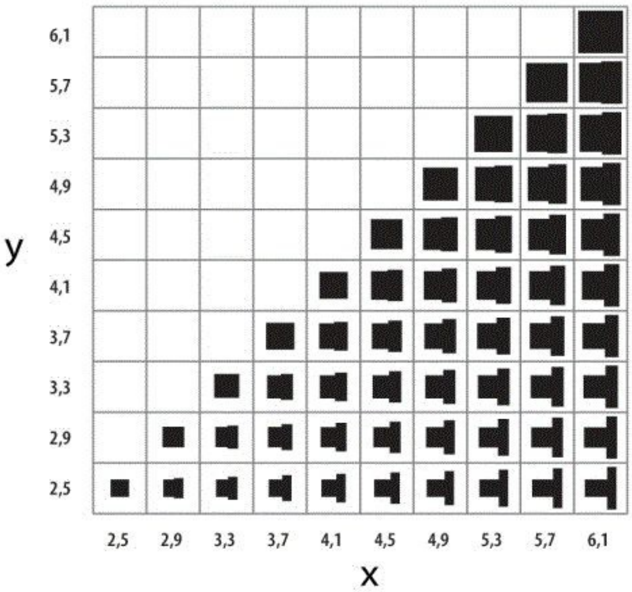

Figure 10. Proportional evolution of shape. Source: authors.

The result of applying these characteristics in the equation of evaluation of energy efficiency level was 9% of models with level of efficiency A, 87% level B and 4% level C for 55 cases. In Figure 11, we have the relative energy efficiency of housing units from the average energy efficiency for summer (CDH) and, in Figure 12, the average performance for winter (CH).

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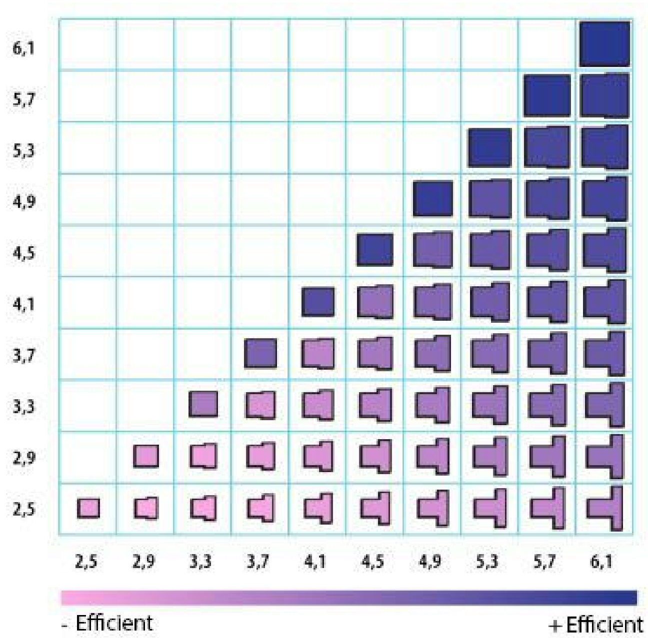

Figure 11. Scale of cooling degree hours (CDH) as a consequence of the dimensions of the HU. Source: authors.

It can be seen that the indicator which determines the efficiency for winter – relative consumption for heating - has not changed following the volumetric variations, enabling the level A of efficiency in all the models. Regarding the indicator for determining the efficiency for summer - Cooling Degree-hours (CDH) of Equation 1 - the envelope efficiency improved with the increase of floor area. However, the efficiency has not been modified only by this factor, as the HU's with rate 1 (x = y) showed higher energy efficiency in comparison to other HU's with the same floor area. The calculation of compactness index of 55 units did not show remarkable direct relationship regarding to the efficiency of the envelope, except in cases mentioned previously (x = y). Although a limited number of models of this study reduced possibilities to find any relationship of compactness with efficiency, it is believed that the area of openings - considered fixed in this study - is a variable that alters the correlation of compactness index with efficiency.

These results indicate the sensitivity of the equation for Bioclimatic Zone 3 to the shape of the building. Although the shape has impacts on performance for both summer and winter in the international literature, it makes sense that the sensitivity of shape in the equation is greater in the summer, since the Brazilian winter is not severe and conditioning mode is natural, in general. It should be noted that the basic model of the HU followed bioclimatic principles of distribution of rooms, with wet areas at west, which also helped to protect the EPR in the summer. As the regression equation was generated considering a basic occupancy of 2 people per bedroom (Sorgato, 2009; Versage, 2009), it is believed that the internal heat generation has helped the stabilization of the performance in winter, which eliminates the sensitivity of the efficiency to the shape at this season. In contrast, the performance of HU in summer depends on larger openings for dissipation of internal heat. Larger rooms generated larger openings areas and, therefore, greater potential for ventilation. Additionally, the stratification of the plant - or low compactness - showed worse results for summer due to exposure of more exterior wall areas to the exterior environment.

The advantage of using the regression equations for analysis of shape was the speed and simplicity of the method for investigation of trends, whose computer simulation overloads research time and costs. Parametric simulation in the area of energy efficiency faces a time of analysis of a large number of variables which generation of results drives to the statistic approaches discussed previously. The regression equations of the RTQ-R (Brazil, 2012) were generated by parametric simulation - based on residential architecture in the country - and were implemented to the Brazilian climates, ensuring the representativeness and reliability of results. Its use is justified to speed up the verification of the trends of performance using few parameters and also to enable the creation of a shape grammar focused on energy efficiency. Later, simulations using thermal-energy software can be used for the implementation and confirmation of a grammar previously built with the use of regression.

6. CONCLUSION

The study of volumes can lead to significant differences in energy efficiency for summer conditions when performing parametric simulations of shape of housing units with multivariate linear regression models. However, for winter conditions, there was no significant change in efficiency. It was seen that the sensitivity of the energy efficiency to the shape of the housing plan is higher for summer conditions than for winter in Bioclimatic Zone 3, with variations of efficiency levels from C to A on summer, and no variation on winter. However, the increasing of volumes of HU on the 3rd dimension, including the ceiling high and the change in slope of the roof as parameters candidates to variation, is also desirable. The Brazilian architecture already has simplified tools, such as the PBE Edifica regression equations, and others more complex, such as simulations, for the creation and operation of constructive and formal characteristics of the housing.

Such methods tend to direct the energy performance studies and, consequently, the creation of the project design to a more complex level, but still fast and reliable. Such studies should generate products whose solutions involve, for example, spatial arrangements of indoor rooms or climatic parameters that affect the energy performance, as well as guidelines for occupancy on the building surroundings.

In this study, a simplified tool from RTQ-R, referring to its prescriptive method, was used to explore performance trends caused by shape, which showed the need for greater attention to summer conditions. The performance for that weather conditions should be a priority, since the other parameters such as material properties, guarantee the basic conditions for the winter. An initial language for creating a shape grammar was observed, which reduced the time spent in the research in relation to complete computer simulations. Finally, it is observed that the simple stratification of rooms does not necessarily determine a good performance to naturally ventilated housing, which is a warning for users of RTQ-R.

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