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MULTICRITERIA DECISION TOOL TO ASSIST IN DECISIONMAKING OF HOUSING ENVELOP SOLUTIONS AND HEATING WATER SYSTEM

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ABSTRACT

Nowadays it is relevant to improve the thermal-energy performance in housing envelopes and heating water systems, assuming or not an acceptable increase in costs. This issue is due to the growth of electricity demand expected in the residential sector for the next two decades. The objective of this research was to develop a multicriteria decision tool to assist in decision making about housing envelope solutions and heating water system during the initial stages of the building venture. It associates national energy policy issues, building costs, thermal-energy performance simulation and multicriteria analysis. Then creates a database that puts together the information that will be analyzed by the ELECTRE-III method. The analysis result is a ranking of the building solutions evaluated. Thus, it becomes possible to list the building solutions during the initial stages of design. This is helpful for designers and investors (private and public) because the method offers a solutions ranking based on in costs and benefits, which certainty helps to choose solutions with better thermal-energy performance within the budgeted cost.

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INTRODUCTION

There is a known and latent demand for housing construction in developing countries. Countries with most fragile economies, such as Brazil, need to make a major effort to reduce this deficit. In 2017, there is demand for more than 6 million housing units in Brazil (FJP, 2016). The challenge of producing such a large number of buildings often leads to public policies with short-term views based only on the number of homes delivered. Developing countries, whose energy infrastructure also requires massive investments to support economic advances, should strategically prioritize the production of housing with the lowest possible energy impact. The development of planning tools for housing enterprises capable of dealing with the thermos-energetic performance of the dwellings from the initial stages can contribute to the elaboration of long-term public policies that integrate the reduction of the housing deficit with the efficient use of energy. Sixteen years after Law 10,295, of October 17th, 2001 (Energy Efficiency Law) (BRASIL, 2001), the results achieved in the country can be considered very timid. It is perceived that the state worked to develop policies to promote rational energy use tools in buildings. However, it can be seen that the disconnection between these policies is significant. PNEf itself (MME, 2011) points out this problem, but does not arrive at the proposition of objective measures to overcome it. In addition, it is perceived that the assessment of this issue from the economic point of view continues as a gap. Knowing the thermo-energetic performance of buildings and the costs associated with their improvement allows the country to formulate energy-efficient housing policies in a consistent and responsible manner. Usually in Brazil, the decision process that makes feasible the realization of real estate projects has three main actors: the planners who develop the quality analysis of the housing enterprise that will support the decision, the investor (who can be the end user or not) and the public power in two scales: municipal, by means of the

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legislation of use and occupation of the ground and the codes of works and federal, through the policies of housing financing. Generally in Brazil, it is done the conceptualization and definition of the new houses arbitrating construction costs that disregard measures for the improvement of thermos-energetic performance as can be perceived by NBR12.721: 2006 (ABNT, 2006). In later stages of the project, when these issues are eventually raised, the budget is already established. So demands for improved thermos-energetic performance need to compete with other demands so that they all fit the previously defined budget. Multicriteria Analysis Tools - MCA - in the early stages of project development can help break this cycle that puts the decisions of thermos-energetic performance often as addendums to the original budget. In complex projects situations, such as real estate developments, that involve multiple criteria, inaccurate data, various decision makers, and, different goals, multicriteria analysis can provide decision making in an objective manner. In addition, according to Wang et al. (2009), decision analysis is a method capable of carrying out an integrated evaluation of the sustainability aspects (economic, environmental and social). In this context, this work aims to present a tool to aid the decision of building design and thermos-energy performance based on a multicriteria analysis method that simultaneously considers technical criteria of water heating for bath and thermal performance of the envelope and economic, applicable to all regions of the country and constructive typologies.

MATERIALS AND METHODS

To address the problem identified, the ELECTRE III method showed adequate characteristics to construct a response. Govindan and Jepsen (2016) demonstrate that ELECTRE-III is the most usual method applied in energy management, natural resources and environmental control among those of the same family. Basically, this variation of the ELECTRE method has two stages of application: (i) construction of relations between alternatives and (ii) exploration of relations to establish the final ranking (WANG et al, 2009). This method is still able to evaluate the alternatives in a discrete way from a quantitative and qualitative point of view. The ranking is done by choosing the alternatives that have a level of agreement and a lower level of disagreement between the criteria. This selection is made by successive comparisons between two alternatives, so that those that are less favorable are eliminated and preference is given to the more favorable ones (ROY; BOYSSOU, 1985). Among the works that have used ELECTRE-III, it is worth mentioning the application of Matulaitis et al(2016) to analyze the effectiveness of different policies for the implementation of domestic photovoltaic systems in several European countries based on economic and environmental criteria. The results were able to point out weaknesses and potential of the policies implemented in these countries. The work of Catalina et al(2011) uses ELECTRE-III to assist in the decision on the renewable energy system most appropriate to the situation analyzed. It considers as criteria: economic aspects, energy performance and impacts on the environment. The authors conclude that the methodology made evaluations that were complex and fraught with uncertainties easier. Piguet et al(2011) use ELECTRE-III to integrate a broad methodology developed to include aspects of sustainability (use of renewable energy sources) in the master plan of the Praille-Acacias-Vernets suburb located in Geneva, Switzerland. The general method consists of (i) establishing a geographic database using GIS, (ii) identifying, locating and quantifying available energy resources, and (iii) identifying and discussing all synergies and conflicts raised. The ELECTRE-III was used as an auxiliary during the decision process that created ranking for the energy scenarios considering the criteria and weights established by the actors involved. The methodology developed was able to identify the potential and feasibility of using geothermal energy in that locality. Avgelis and Papadopoulos (2009) present a method for choosing and managing the air conditioning system (HVAC) considering the best possible condition for an office building located in Thessaloniki, Greece. They associate the multicriteria analysis (ELECTRE-III) with the computational simulation of the building to make an ample evaluation of the system. The results show that it is possible to classify the design alternatives taking into account simultaneously economic, energy, environmental and user satisfaction criteria. In Brazil, ELECTRE-III was used by Castro (2005) to produce software to aid architectural design in the classification of design alternatives for office buildings in Rio de Janeiro. The code of this software was the basis for the development of RESIDE. The computational application developed has a simple interface to be used by the designers during the design phase (CASTRO, 2005). However, according to the author, the construction of databases can make it difficult to use in architectural offices. Fontenelle and Bastos (2014) applied the application developed by Castro (2005) to highlight the contribution potentials of the multicriteria approach in architectural design.

Methods

The entire method for developing the work was based on ELECTRE-III, developed by Roy (1977), who builds his ranking from a preference relation. Two alternatives are compared at a time to identify (i) a strong or weak preference for one of the actions, or (ii) indifference between actions, or (iii) incomparability between actions. The evaluation of each action or alternative ai (i = 1,2, ..., n) by the multiple criteria adopted, Cr1, Cr2 ..., Crm, is done by a vector with multi attributes {ei1, ei2, ei3,. .., eim}. The preference limit "P", which indicates the difference from which a strict preference can be established between two evaluations, and the indifference limit "Q" that indicates the difference from which no preferences can be established between alternatives. characterize the situations. To define the incomparability between actions, the veto limit "V" is used for each criterion, representing the difference from which one should ignore the comparison between two actions. These limits can be calculated from standard equations defined in Roy (1977).

In order to set up the evaluation matrix, we need: (i) the list of alternatives, (ii) the criteria and their respective weights, and (iii) the definition of the abovementioned limits. The method is based on a binary relation of overclassification (subordination) defined from the set of alternatives. Two tests are performed: agreement and disagreement on the hypothesis if alternative "A" overclasses (subordinates) the alternative "B". The concordance test establishes whether there is most criteria favoring "A", and the discordance test establishes whether there is not a strong minority in favor of "B", making the hypothesis true. After the calculations, two matrices are constructed, one for agreement and one for disagreement, where all possible pairs of "A, B" shares are compared. From this comparison comes the third matrix, the credibility matrix, which assigns a quantitative measure for the veracity of the

Table 1. Alternatives to Vertical Fence Construction Systems

1	Acrylic painting white snow matte + plaster and mortar plaster of cement and sand (2.5cm) + block ceramic sealed hollow (14cm) + plaster projected (0.5cm) + acrylic paint white snow matte
2	Acrylic painting white snow matte + plaster and plaster mortar of cement and sand (2.5cm) + concrete structural block (14cm) + plaster projected (0.5cm) + acrylic painting white snow matte.
3	Acrylic paint white snow matte + plaster and mortar plaster of cement and sand (2.5cm) + autoclaved cellular concrete block (15cm) + projected plaster (0.5cm) + acrylic paint white snow matte.
4	Acrylic painting white snow matte + molded concrete wall in loco (10 cm) + projected plaster (0.5 cm) + acrylic paint white snow matte.
5	Acrylic paste for snow white external coating + Surface mesh + Cement sheet (1 cm) + Tyvek + Guide profile and profile in galvanized steel + plasterboard (1,25cm) + acrylic paint matte white snow
6	Acrylic paste for snow white external coating + Surface mesh + Cement sheet (1 cm) + Tyvek + Guide profile and profile in galvanized steel + mineral wool + plasterboard (1,25cm) + acrylic paint matte white snow

Table 2. Alternatives of constructive systems of coverage

1	Concrete slab with cover waterproofing not subject to fissures and transit based on acrylic emulsion structured with polyester veil; protective mortar for waterproofing; and thermal insulation in slab using vermiculite agglomerated with cement and sand e = 15cm - unit m²
2	Concrete slab with fiber cement roofing, one water, corrugated profile, e = 6mm, height 125mm, useful width 1020mm and nominal width 1064mm, slope 27% - unit m²
3	Concrete slab with fiber cement roofing, one water, corrugated profile, e = 6mm, height 125mm, useful width 1020mm and nominal width 1064mm, slope 27% - m² unit with undercoat in aluminum foil
4	Concrete slab with fiber cement roofing, one water, corrugated profile, e = 6mm, height 125mm, useful width 1020mm and nominal width 1064mm, slope 27% - unid. m² with thermal insulation employing fiberglass blanket, e = 5cm - unit. m²
5	Concrete slab with thermoacoustic tile cover, trapezoidal profile, e = 30mm, height 70mm, useful width 1000mm and nominal width 1056mm - m² unit
6	Concrete slab with cover waterproofing not subject to fissures and transit based on acrylic emulsion structured with polyester veil; protective mortar for waterproofing; pre-vegetated ecstatic honeycomb system with substrate (installation included)

Table 3. Alternative of water heating systems for bathing

	Heatsource	Distribution	Type	Equipments	Pipes
1	Solar	SF	Accumulation	Showers, solar panel, tank and back-up system	HW andCW
2	NG	SF	Passage	Showers and heater	HW andCW
3	LPG	SF	Passage	Showersandheater	HW andCW
4	Electric	Unit	Passage	Showersandheater	CW
5	Electric	SF	Passage	Showersandheater	CW
6	Electric shower	Unit	Passage	Showers	CW
7	NG	SF	Accumulation	Showers, heater andtank	HW andCW
8	LPG	SF	Accumulation	Showers, heater andtank	HW andCW
9	Electric	SF	Accumulation	Showers, heater andtank	HW andCW
10	Solar	MF	Accumulation	Showers, solar panel, tank and back-up system	HW andCW
11	HB	MF	Accumulation	Showers, heat bomb and tank	HW andCW
12	NG	MF	Accumulation	Showers, heater andtank	HW andCW
13	LPG	MF	Accumulation	Showers, heater andtank	HW andCW
14	Electric	MF	Accumulation	Showers, heater andtank	HW andCW

Subtitles: NG – Natural Gas; PG – Liquide Petroleum Gas; HB – Heat Bomb; SF - Single Family; MF – Multifamily; HW – Hot water; CW – cold water

Table 4. Weights assigned to criteria

Symbol	Criteria	Weights
Cr01	Percentage of passive thermal comfort hours	2
Cr02	Condition of natural cross ventilation	3
Cr03	Number of degrees-hours for cooling	1
Cr04	Cost percent variation of envelope solutions	3
Cr05	Government incentive for the use of bath water heating technology	3
Cr06	Degree of complexity of the complete infrastructure of the bath water heating system	2

hypothesis "A" overclassifies "B". The ranking of alternatives is established based on the credibility matrix. The ordering is done by a distillation procedure, that is, the alternatives are positioned according to their decreasing classification (best to worst). According to Buchanan *et al*. (1999), ELECTRE-III is distinguished from other multicriteria methods by performing non-compensatory analysis and by allowing incomparability between alternatives. The critical item for the application of ELECTRE-III is the construction of databases of alternatives representative of the reality of analysis. In order to be applied in a regular way on a national scale in the housing market and in municipal, state or federal public policies, it is necessary to develop data banks contemplating the specificities of the area of coverage in order to cover the characteristics of the objects analyzed, such as: local climate, thermal comfort requirements of users, cost data, and current legislation. For the proposed method, this construction is based on thermo-energetic simulations, current costs of construction materials and services and determinations present in the relevant public policies. Each database consists of a list of alternatives for feeding the multicriteria analysis tool, which includes different formal and technical solutions for the water heating and envelope system. The alternatives of architectural solutions to be examined can be differentiated by the variation of the following parameters: (i) orientation of the building, (ii) condition of natural ventilation, (iii) windows size, (iv) presence of sun protection in the openings, (v)opposite or adjacent facades opening ratio,(vi) enclosure sealing system (walls and cover) and (vii) water heating system. It is necessary to create databases with distinct architectural formal typologies by the number of units, relation between floor plans and height and price ranges. The variable items for the composition of the alternative are detailed in the sequence.

RESULTS

Database

Orientation: There are eight ranges of guidelines for the implantation of the facade considered the front of the building, always in relation to True North (NV), namely: North (337.5° to 22.5°); Northeast (22.5° to 67.5°); East (from 67.5° to 112.5°); Southeast (from 112.5° to 157.5°); South (157.5° to 202.5°); Southwest (202.5° to 247.5°); West (from 247.5° to 292.5°); and Northwest (292.5° to 337.5°). The results of the thermos-energetic performance simulations of the buildings that are part of the database were performed for the main orientations: North (0°); Northeast (45°), East (90°), Southeast (135°), South (180°), South West (225°), West (270°) and North West (315°).

Openings size: The definition of opening areas considers two ranges. The firstrange is composed of openings less than or equal to 20% of the floor area of the room and called average openings. The second range defines openings that are larger than 20% of the floor area of the room and are called large openings. Openings of less than 16.7% are at odds with most of the country's building codes that determine at least 1/6 of floor area in extended permanency rooms (BUSON, 1998).
The standard window frame model used is running with an effective venting area of approximately 45% of the span area. This decision was based on the standard materials established in NBR12.721:2006 to calculate the Basic Unit Cost of Construction (CUB) (ABNT, 2006). Variations in opening shapes and materials certainly impact the performance and cost of the envelope. However, it is understood that in this stage of the enterprise this is an item not yet defined.

Openings shading: It was decided to address the issue in a simplified way, allowing the option of totally shaded or non-shaded openings for extended permanencyrooms, bedrooms and living rooms. The total shading for the simulation files was provided by a venetian blind made of natural anodized aluminum plates located external to the glass, being permeable to ventilation.

Opposite or adjacent facades opening ratio: This is a binary parameter which should be true only if more than sixty percent of the units have openings in opposite or adjacent facades or false otherwise.

Constructive systems: In order to define the alternatives, it was chosen the most frequently used systemsemployed in the construction of multifamily projects in Brazil. Six solutions were selected for the vertical sealing and six solutions for the roofing system.

Water heating systems for bathing: The list of alternatives for bath water heating systems considers options that cover the three most commonly used energy sources in the country according to PROCEL (2007). For each of these heat sources, different types of heating (passage and accumulation) and distribution (single, single family and multifamily) were chosen. Table 3 presents the 14 options available foranalysis.

Definition of Criteria and Weights: To perform the analyzes, six criteria were established with the objective of defining the individual performances of each project alternative, namely: (i) percentage of hours of passive hygrothermal comfort; (ii) natural cross-ventilation condition; (iii) number of degrees-hours for cooling; (iv) percentage variation of the cost of the enveloping solutions; (v) government incentive to use bath water heating technology and (vi) degree of complexity of the complete infrastructure of the bath water heating system. The percentage of hours of passive hygrothermal comfort (PHCH) for summer wasdetermined on the basis of computational simulations of building modelspresent in the NBR12.721: 2006 (ABNT, 2006) from the calculation of the neutral temperature. The computational simulations for thermos-energetic performance were made using the Conduction Transfer Functions (CTF) method of the EnergyPlus^{TM} program. The climatic files used were of type TMY-2 (Typical Meteorological Year) for the reference cities of each database. Envelope modeling considered each extended permanency rooms as a thermal zone. In cases where there is attic, it was also modeled as a thermal zone. The simulation file has all the floors of the building, all the existing openings and the balconies of the housing units. All the thermal characteristics of the constructive elements were inserted. In relation to the simulation parameters of the natural ventilation, the roughness coefficients of the environment were used, in this case it is considered a land in urban center, the pressure coefficients in the surfaces are calculated automatically by the program.The numerical values of the discharge coefficient, the airflow through gaps and its exponent are, respectively: (0.60); (0.001 kg/s.m) and (0.65). The strategy of automatic temperature control was used, that is, whenever the indoor air temperature is higher than 20°C, the windows and doors of extended permanency roomsremain open (except the door to the unit that remains always closed). According to the work of Loura (2006), this CTF calculation method presents some interferences in the outputs (results) when simulations are performed with a very low air renewal rate in naturally ventilated buildings. To avoid this problem, the windows of transitory rooms (bathrooms and kitchen) were kept open 100% of the time. The minimum occupancy pattern, the activity metabolic rate, the installed lighting power densities and the internal equipment loads presented in the RTQ-R (INMETRO, 2012), as well as the ground temperature determination method were adopted. The PHCH for each environment of a housing unit corresponds to the ratio between the sum of the number of hours of comfort throughout the year and the total number of hours of the year. The average value for each housing unit is calculated by means of a weighted average relative to the area of the environment. The final result was the average value of each unit. This criterion is quantitative with directly proportional evaluation.

The number ofdegrees-hours for cooling (GHR) was also obtained by means of computational simulation using EnergyPlus from the operative temperature of the extended permanency rooms. The calculation of degree-hours of cooling per year was done according to the RTQ-R methodology presented in INMETRO (2012), considering the average weighted by the area of each room to calculate the value of each housing unit. From the averages of the housing units of the lowest and the highest floor the average value for the building is calculated. This criterion is also quantitative with an inverse proportional evaluation. The work of Loura et al(2015) has shown that the impact of natural ventilation on thermos-energetic performance is in some cases more significant than the thermos-physical characteristic of the envelopes. Therefore, it is proposed a criterion on binary natural ventilation that can verify if a minimum strategy to promote cross-ventilation will be present in the housing produced. The decision-maker shall indicate whether 60% or more of the autonomous units have external openings on opposite and/or adjacent façades. The cost of the envelope solutions was determined by market price survey of the constructive solutions compositions using the SINAPI -

National System of Survey of Costs and Indices of the Civil Construction (CEF, 2017). This criterion is quantitative with an inverse proportional evaluation. The composition present in NBR12721:2006 was defined as an alternative for reference envelope. This alternative reference consists of 9 centimeters ceramic blocks with internal and external coatings for vertical sealing and fiber cement roof tile with wood structure on concrete slab.

The percentage variations of the costs of the envelop alternatives were calculated from the ratio between the cost of each alternative and the cost of the reference alternative (for both masonry and roofing). Considering the five masonry options and the six coverage options, thus, a total of 30 combinations were evaluated. According to Goldman (2004), the incidental percentages of costs related to roofing and masonry services show significant variations due to typology, standard, etc. For the roofing, the change is from 0.3 to 1.1%. For masonry, the variation is from 3.0 to 6.5% of the final value of the construction work services. In order to give homogeneity to the comparisons, it was considered, for the calculation of the total variation of each alternative, a weight of 75% for the masonry and 25% for the roofing. The values of the alternative references (masonry 1 and roofing 2) were considered 100, the values of the other alternatives are equivalent to the percentage difference of the cost of this alternative in relation to the reference. The government incentive criterion for the use of bath water heating technology considers three classes of incentives by the government to use the technological alternatives for bath water heating, listed based on PNEf (MME, 2011) and on RTQ-R (INMETRO , 2012). These classes were assigned values considering the comparability characteristics of the ELECTRE-III method. The first class was established the lowest value (equal to 10) indicating that these systems are not encouraged by public energy policies. The second class corresponds to the value 20 and is composed of the intermediate systems. The third class is composed of systems most encouraged by national policies and receives the highest value (equal to 30). This is a qualitative criterion with directly proportional evaluation. Finally, the criterion degree of complexity of the complete infrastructure of the bath water heating system, it is also qualitative, but with an inverse proportional evaluation. Three degrees of complexity were established for the execution of the water heating system.

For the one who presents less complexity, the value (10) was assigned, being this group composed of single distributionsystems, such as the electric shower. The single-family systems are classified as intermediate degree of complexity (20). And the multifamily systems are the most complex (30). After defining the criteria, the weights are distributed for each one, based on the objectives of the analysis performed. The judgment scale is composed of three classes according to the relevance of the criteria: class 1, class 2 and class 3. Criteria with relevance class 1 have less weight in the analysis and criteria with relevance class 3, greater weight. Relevance was established based on the impact of a certain criterion on the interest of the actors involved in the process of housing developments, namely: public power (energy sector and housing sector), developers, builders and users. Table 4 shows the weights.

Software Reside: The software RESIDE – Intelligent Decision for Residential Projects was created for Windows® XP/Vista/Seven/8/10 platform, developed in C#, based on the methodology of multi-criteria analysis method Electre-III. The Windows Forms and SQLite libraries were used on the implementation, respectively, of the graphic user interface and the database. The algorithmic base was the program CELECTRE, developed by Castro(2005), which was created to implement the multi-criteria analysis method Electre-III in computational terms. The adaptation of CELECTRE's source code was authorised by the developer, Eduardo Breviglieri Pereira Castro. The RESIDE allows the user to analyse up to sixteen set of parameters or actions at a time and save them for eventual future use. Users can choose an existing database or create their own. The program's functionalities can be seen in the Figures 1 and 2. The Figure 1 shows the characterization of the actions step, the list of criteria and its weights. It also shows how the characterization is presented after its insertion in analysis list. If it is in the interest of the user to deactivate any of the listed actions, it is possible to do it by checking the correspondent box on the side column of the actions' grid. Each database has eight reference cases, one for each orientation, and they were established based on the housing envelope solution standard present in the NBR12.721:2006 (ABNT, 2006) and on the most used water heating system in the context of the database. It is worth noting that the simulation will only start with the reference cases among the analysis' alternatives. Therefore the user must consider the number of reference cases to know the maximum quantity of actions that will be analysed at a time.

For example, the user may choose fifteen different solutions if all of them have the same orientation, as there is only one reference case by orientation. On the other hand, if the intention is analysing the eight different orientations, it will be necessary eight reference cases. According to Tervonen et al(2005) the definition of weight is one of the most important parameters for the realization of the multi-criteria analysis using ELECTRE-III. Therefore, it is proposed for verification of the ranking's validity a sensibility analysis changing the criteria weights. The variation index is defined by the user and the program accepts any positive rational number. Furthermore, the user needs to select which criteria should be analysed. The value entered by the user is added to the weights of the criteria of interest. Considering this new weights distribution, a new multi-criteria analysis is done and a new ranking established. In the figure 1, the sensibility analysis added 2 unities to the natural ventilation weight. The objective of the sensibility analysis done after establishment of the ranking is to evaluate the stability of the shown ranking. The figure 2 shows the list of available options for the user, the limits definition panel, the sensibility analysis configurations, the ranking calculating button and the exhibition of these.

The characteristics of the method ELECTRE-III, based on the noncompensatory analysis and the incomparability among solutions, are very relevant in giving confiability to the outputs shown on RESIDE. They prevent the favoring of solutions or actions highly valued in a/some criterion/criteria and poorly valued in the others. As the used criteria interest in different ways the distinct actors involved in building planning, the noncompensatory analysis tends to protect the favoring of criteria of interest on the part of those involved in relation to the neglecting in other criteria of interest on the parties with less decision power in this project phase, for instance, the user.

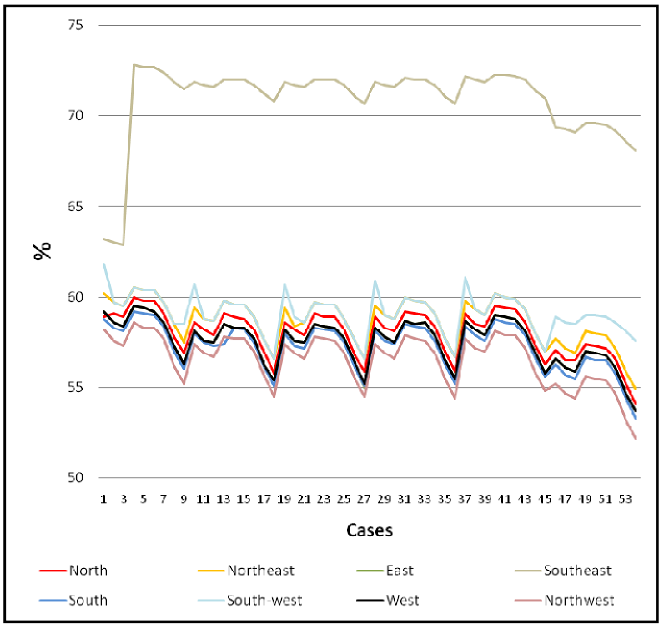

Figure 1. Percentual Comfort Hours for Windows with solar protection

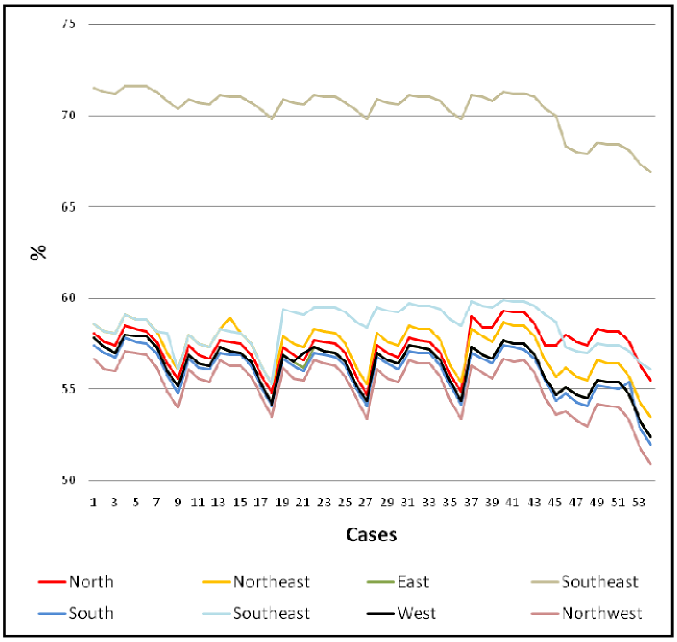

Figure 2. Percentual Comfort Hours for Windows without solar protection

The databases used by RESIDE are generated using the SQLite library and have three tables: (i) the first with nine hundred and sixty cases, one for each set of orientation, opening, shadowing, wall solution and roof solution; (ii) another one for the heating systems including fourteen cases; (iii) the last one for the ventilation, with 16 cases, one for each pair of orientation and rate of openings on opposites or adjacents facades. It is necessary to build one new database for each climatic or economic context and also for each building typology. Two of the database's informations, namely Cr01 (percentage of thermal comfort hours) and Cr02 (cooling degree-hours), are results from computational simulations, with nine hundred and sixty simulations being necessary for one database. Secondary information which are part of the method's output to establish the ranking, such as concordance matrix, discordance matrix etc., are not available in RESIDE's interface. They were suppressed because they (i) are difficult to understand by the user which do not know the method deeply, (ii) their analysis don't bring relevant information to the decision making, and at last, (iii) because their presence could make the immediate reading of the ranking difficult. In relation to the credibility of the results, it is interesting to comment that the sensibility analysis allows the verification of the ranking's behavior faced with the variation of the weights. Thus, the user can perceive if the ranking do or don't suffer changes. During a negotiation, this kind of information is relevant and must be available for the decision makers. Furthermore, the advanced multi-criteria tool user can resort to the credibility matrix if any doubt arises in relation to an established ranking.

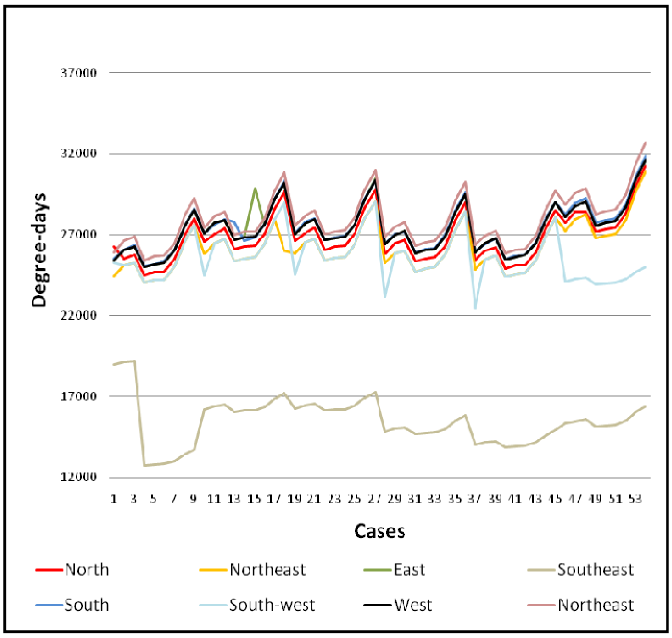

Figure 3. Degree-days for windows with solar protection

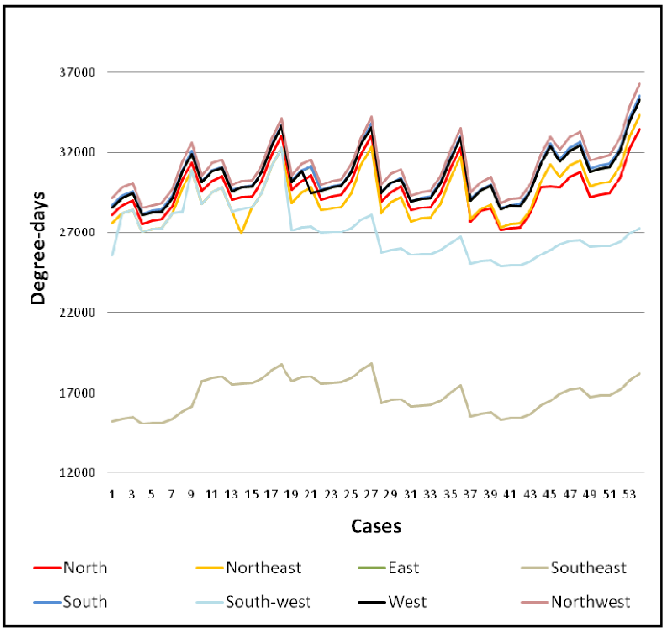

Figure 4. Degree-days for windows without solar protection

DISCUSSIONS

RESIDE's development demonstrates that the goal has been achieved. And the proposed methodology contributes to broadening the scope of works, still scarce in the country,

which treats the thermal-energy performance in housing objectively in the development planning early stages. In other to achieve these results the integration of different takes into the traditional development planning: (i) the energy concept of building, (ii) the thermal-energetic simulation and (iii) the multi-criteria analysis. The software RESIDE adapts to planning and decision dynamics on new housing developments once it offers direct and agile responses on the performance of formal solutions, construction systems and water heating systems in relation to six criteria. It can be pointed as advances in the methodological process proposed (i) the public agent (government) insertion as one of the parties during the process of decision making (in the definition of the criteria weights) in the early stages of housing development projects and (ii) the consideration as a decision criterium aspects related to current public policies, such as the governmental incentives for heating water technologies. Thus the methodology provides an approximation between the public policies and the interests of incorporators. The procedure is considered appropriate for all kinds of housing building investors, both private and public.
The database developed for Rio de Janeiro shows relevant guidelines to public sector and the real estate industry. The analysis bespeaks how important is the ventilation impact on the thermal comfort condition and the cooling degree-days. On the other hand, the envelope solutions performance indicates that there are no relevant gains in thermal comfort despite the different costs. The figures 1 to 4 summarize data for all envelope options evaluated. Considering that the bioclimatic zone evaluated, that includes Rio de Janeiro, reaches 50% of the Brazilian territory, it is possible to infer that: (i) it is necessary to review the country regulations in order to incorporate criteria capable of indicating gains in dwellings due to natural ventilation in hot and humid climates; (ii) urban plans should include natural ventilation as criterion for urban densities evaluation and (iii) it is very important for entrepreneurs and designers the correct building orientation to promote satisfactory use conditions. Among the limitations of the procedure stands out the non inclusion of the final uses, cooling, cooking and lighting, also meaningful in residences. However, with minor relevance to the development project than the selected ones. There are also, temporarily, a limitation to three databases which contemplates two typologies, two economics conditions and two climatic conditions of the country. the work follows aiming the increase in the number of databases to make feasible the use of RESIDE throughout the country. Generally, it can be asserted that was proposed a friendly interface, focused in the description of the actions and the clarity of the results. The RESIDE is capable of producing objective information about the thermal-energy performance of the housing in early phases of project from six criteria which integrate public policies, users and builders interests.

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