ANALYSIS AND SIMULATION OF ENERGY EFFICIENCY OF COMMERCIAL BUILDINGS ENVELOPE IN CENTRAL ZONE OF THE CITY OF PELOTAS-RS

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ABSTRACT

The current energy situation causes concern worldwide on the natural resources conservation. Several countries have already implemented policies for energy conservation that, breaking paradigms, change the way of how to design. This study aims to identify the pattern of the envelope energy efficiency of commercial buildings - stores of the central zone of Pelotas, southern Brazil, based on the computer simulation results. This is an ongoing study but these 16 buildings that fit these characteristics were picked up to a more detailed survey that explains the buildings features like: type of materials used in the building envelope, glass type, percentage of openings on the façades of all building faces. Then the energy consumption of these buildings will be simulated, but it is possible to observe that the buildings of up to two floors, built in lots of mid-block until the 1980s, where light colors on the façades prevail, and the percentage of openings in the façades characterizes the buildings of the city center.

INTRODUCTION

Energy has become a serious issue worldwide because of the energy crisis in the 1970s and the increase of the population in urban centers in the 1980s. To overcome the crisis, the production of energy had to grow significantly since then. Therefore, this alternative brings disadvantages of environmental impact caused by new plants like: possible floods and population dislocation, as for hydroelectric; pollution and the risks with public safety, in the case of nuclear and thermo-electrics. Furthermore, the demand of great investments by the government implies in the reduction of investments in other areas such as health, education and housing, antagonizing the idea of progress included in this policy (Lamberts et al, 2004).

The alternative which is thought to be the most adequate to this scenario is to increase the energy efficiency in the use of energy, since it is quite feasible to save it than supply it, thus it reduces the expenses with the public sector, transferring to the manufacturers of equipments and to consumers the necessary investments. It is worth emphasizing that electricity passes by three different stages until it reaches the building: generation, transmission, distribution and, finally, consumption. The higher the performance of components of each of these stages the lowest the energy loss of the process as a whole. But the conception of projects that make the accomplishment of a more efficient building feasible is the architect's responsibility, this way providing more comfort to users and the rational use of energy (Geller, 1994).

In Brazil, the main mark was the energetic blackout of 2001, since then, the concern about energy saving has increasingly gained space worldwide. After this fact, Law n°10.295 of Energy Efficiency (Brazil, 2001a) was enacted, which is about the National Policy of Conservation and Rational Use of Energy. After the approval of Decree n°4.059 of December 19th, 2001, the Buildings Work Group was created to propose a way to regulate buildings constructed in Brazil, aiming at the rational use of electricity (Brazil, 2001b). Then, Brazil commenced its path towards the change of the paradigm with relation to generation vs. energy saving. Until the energy blackout in 2001, the governmental proposal concerning the energy matrix was clearly based on the increase of the generating matrix, not giving the necessary focus on buildings energy efficiency, since they consume around 42% of the Brazilian energy (Lamberts et al, 2004).

Several studies have already been accomplished with relation to electricity consumption through the final use in commercial and public buildings (Geller, 1994). Commercial and public buildings consume 19% of the national electricity production. From these 19% of energy consumption, an average of 44% is consumed with lighting, 20% with air conditioning equipments and 36% with other equipments (Lamberts et al, 2004).

The main steps fulfilled with relation to thermal performance of buildings became real because of NBR 15220 (ABNT, 2005), which defines the minimum acceptable requirements of thermal performance for housing of social interest, also the Brazilian territory is divided into eight bioclimatic zones, indicating strategies to improve thermal comfort of buildings passively; later, NBR 15575 (ABNT, 2008) determined that buildings of up to five floors were regulated in order to evaluate their performance.

Important steps concerning the approval of the Technical Regulation on the Quality of the Energy Efficiency Level of Commercial, Services and Public Buildings - RTQ-C and the Technical Regulation on the Quality of the Energy Efficiency Level in Residential Buildings - RTQ-R by the Ministry of Mines and Energy were taken into account in order to change the paradigm towards the Brazilian construction industry as for the Energy Efficiency in Buildings.

Voluntary tagging regulation defines that all commercial, public and service buildings must be tagged according to their energy efficiency characterization. The levels of efficiency vary from "A" to "E", where "A" is the highest index and "E" characterizing the lowest efficiency. It was defined in the regulation that each building shall have four efficiency evaluations, where the items evaluated were the lighting system, air conditioning, envelope and building as a whole (INMETRO, 2010).

The RTQ-C presents the criteria for the complete classification of the level of energy efficiency of the building through partial classifications of the envelope, lighting and conditioning system. An equation considers this system through weights established in the regulation and allows to add bonuses to final score that may be acquired with technological innovations, use of renewable energies, cogeneration or with rationalization in water consumption (INMETRO, 2010).

This study aims to identify the pattern of the envelope energy efficiency of commercial buildings - stores of the central zone of Pelotas, southern Brazil, and verify the efficiency of possible deployments of energy conservation measures, based on the computer simulation results. For this, the method used was divided into five parts: Analysis and definition of the types of real models; Specific survey; Envelope Energy efficiency level simulation for each chosen building; Compilation; Results analysis and Proposition for energy conservation measures. This approach meets the topics to be discussed at the conference, adding content and contributing to the applied method and case studies results accomplished in the commercial center of Pelotas.

Pelotas has a subtropical humid climate with well-defined seasons and rigorous winter and summer, showing great climate changes throughout the year. It is located in the south region of Brazil, at 31°46'19''S, 52°20'34''W and it is 7 meters height above sea level. Its annual mean temperature is 17.6 °C and its annual mean relative humidity is 80.7% (Embrapa, 2012). In the context of implementing a new regulation, it is important to publish a new paradigm change as for new prescriptions, and in this sense, mapping and analysis of commercial typologies with relation to levels of efficiency is an important aspect to consolidate a new model of efficiency.

METHOD

This study aims to identify the pattern of the envelope energy efficiency of commercial buildings - stores of the central zone of Pelotas, southern Brazil, and verify the efficiency of possible deployments of energy conservation measures, based on the computer simulation results. For this, the method used to reach the objective of this research will be divided into five parts, which will be detailed as follows:

Analysis and definition of the types of Edificio assessed models

A survey was held to understand what types of buildings are the most recurrent in the center of the city of Pelotas and to define the object of study.

In order to obtain a characterization of typologies located downtown Pelotas, a profile which includes 22 streets which represent the commercial area of the city was defined. In this profile, data from all buildings downtown were surveyed, classified according to function, age, location in the lot, colors of the façades, number of floors, percentage of opaque and transparent envelope, etc. In order to do that, catalographic cards of the buildings, photographic survey and research in the files of the Municipal City Hall of Pelotas are used.

For the selection of the buildings, they were classified according to size, age, position on the court, decharacterization or conservation level in the case of old buildings; and in case of new buildings, if they have exposure of coverage or not. All the chosen buildings have façades facing the north.

The buildings were divided into two groups regarding their size, small and large stores. Small stores have a total area of more than 500m ² and large stores are those with total area of more than 500m ².

The most recurrent buildings in the center of the city are the buildings dated before 1980, however, it is important to evaluate the different construction techniques, new and old, for this reason buildings constructed until 1980 and after 1980 will be analyzed.

Placement on batch interfere in the amount of solar radiation received by the building and the thermal exchanges with the outside, so two types of positioning on the court were considered: the buildings between buildings, constructed in batches of mid-block or those of corner, with or without lateral indentations. The buildings constructed before 1980 were classified into two groups: those considered preserved and those considered uncharacterized. A building is considered preserved if the percentage of façades openings (PAFT) is preserved as the original, the envelope maintained the same thickness and the same original components or characteristics, such as thermal transmittance and thermal capacity. Once the buildings are considered uncharacterized, their changes are PAFT alterations and/or components of the envelope. The constructions built after 1980 are classified as having exposure of coverage or not, or stores that have up to two floors and roofing exposed to the external environment and stores which are located in the ground floor of buildings and which in turn have coverage not exposed to the external environment will be evaluated.

Taking into account the variables involved, 16 different buildings were set up that represent the variables shown in Table 1, in the form of summary of its features and organization of the stores that will be studied.

Table 1

Variables analyzed in commercial buildings

VARIABLES	MODE ANALYSIS	
Stores Size	Small up to 500m²	larger than 500m ²
Age	Antique (Built before 1980)	New (Built after 1980)
Positioning in Quadra	Street corner	Mid-block
Degree of Change	Conserved (original PAFT maintained)	Uncharacterized (PAFT changed)
Coverage Exposure	Coverage Exposed (buildings up to 2 floors)	Coverage Unexposed (buildings with ground floor for the shops)

Specific survey

Preliminarily, we chose 16 buildings that fall within the previously determined characteristics; later, it will be necessary to achieve a more detailed survey which explains constructive features like: type of materials used in the building envelope, their transmittances, colors of external coatings, ceiling height of the ambient, type of internal coatings, frames positioning, type of frames, their materials, type of glass, solar factor; percentage of the façades openings (PAFT) of all buildings faces; lighting and air conditioning system, when these data are available in the projects filled in the city work office, source of research of the specific survey.

Envelope Energy efficiency level simulation for each chosen building

The third stage of the research consists of simulating the buildings analyzed in order to check the level of energy efficiency, considering as comparative reference efficiency levels “A, B, C and D”, that is, real models will be compared, following the project with the ones of reference. To simulate both buildings, criteria which take into account the same characteristics of the real model and the reference model will be adopted, as: same program of simulation, climatic file, geometry, direction with relation to the geographic north, value of ILD in equipments, use pattern of people, with the same value of heat dissipated, air conditioning system will be used, therefore, the COP established in the model of reference according to the level of efficiency intended, same use pattern and systems operation ; the pattern of use will be according to the use and real occupation of the building.

English Software DesignBuilder will be the computer program of thermo-energetic simulation, which algorithms are compatible with the requirements validated by ASHRAE (1993), verifying the yearly modeling of 8760 hours with occupation hourly variations, power of lighting and equipments and air conditioning systems, as well as observing modeling of thermal multi-zones, it models effects of thermal inertia. In the end, the results will be compiled, aiming at the verification and comparison with the process of tagging achieved with real models.

Model building assessed

The model that represents the real building must have all characteristics of buildings according to the project proposed (transmittance of wall and coverings; type of glass, PAFT, absorptance of walls and coverings, VSA, HAS) in the case of the real building to have different air conditioning systems, all different systems in each thermal zone must be represented: utilizing the Density of Lighting Power of the project proposed; considering the devices of shading when they were coupled in the building proposed; shading from the envelope may be part of the method of simulation (optional use) and, when it is used, it must be included in the real building model only.

Models of Reference

The models of reference will be simulated, considering that: the envelope must reach the level of classification intended, that is, level A. The equation, which volumetry indicated is similar to the one of the project, will be used, and value of the Envelope Consumption Indicator (ICenv) of the maximum limit of the classification level interval desired will be adopted. If Factor Form (Rate between the area of the envelope and volume of the building) of the building projected is over or lower Factor Form limit of the equation, limit value will be used; in the general classification, the model of reference must reach the level of efficiency intended according to the weights distribution in the equation of the general classification, Equation (1).

Maximum values of thermal transmittance and solar absorptance to the level of efficiency intended and specific pre-requirements of the envelope will be used; a PAFT (percentage of the façades openings) calculated according to: the formula of ICenv related to the envelope of the building proposed according to the Bioclimatic Zone of the building location will be adopted; Adopt VSA=0 and HAS=0; Adopt a simple glass of 3 mm, with a solar factor of 0.87.

The value of PAFT must be the greatest as possible to the level of efficiency intended. In the case of existing zenital lighting with POZ (Percentage of Opening Zenith) greater than 5% in the real model, the models of reference to the levels A and B must have POZ of 2% with light glass and solar factor of 0.87; the density of the Lighting Power must be modeled in the maximum limits tabled according to the function and W/m², depending on the environmental index, activity and level of efficiency intended; adopt the same Air Conditioning System proposed in the Real Model.

PT = 0.30.{(EqNumEnv AC A A A 5
A C A E m 0 30
E mD 0 40 E mCA AC A
A A 5 A C A E m b
(1)

PT - Final Score;
EqNumEnv - numerical equivalent of the envelope;
EqNumDPI - numerical equivalent of the lighting system, identified by acronym DPI, of Lighting Power Density;
EqNumCA - numerical equivalent of the air conditioning system;
EqNumV - numerical equivalent of non-conditioned and/or naturally ventilated environments;
APT - useful area of ambient of temporary permanence, since they are not conditioned (m²);
ANC - useful area of non-conditioned ambient of prolonged permanence, where the percentage of occupancy hours of comfort by natural ventilation (POC) through method of simulation (m²) was evident;
AC - useful area of conditioned ambient (m²);
AU - useful area (m²);
B - punctuation obtained by bonuses, which vary from zero to 1;

The general classification includes all systems plus bonuses and they refer to the whole building or a part of it. The partial tags refer to the efficiency of the systems separately; the general tag is defined by Equation (1) that contains weights to balance the relationship among the systems, these weights are shown in Table 2.

Table 2

VARIABLE	WEIGHT
Lighting System (DPI)	30%
Air Conditioning System (ACS)	40%
Envelope (Env)	30%

Compilation and results analysis and proposition for energy conservation measures

Based on the analysis of the simulation process of commercial typologies chosen as sample of analysis in the city of Pelotas-RS, the results will be contextualized and the comprehension of the aspects as a whole involved in the analysis of the energy efficiency of buildings will be possible. In this stage, possible strategies of energy performance improvement of typologies will be analyzed, in the envelope of the buildings in question, considering the variables of these buildings envelope. Aspects such as the need for solar protection, variation of transmittance, thermal capacity, and change in absorptance factor closing transparent solar envelope should be analyzed (Table 3), using again the computational simulation tool to check these improvements.

Table 3

Possible Measures and Energy Conservation

POSSIBLE MEASURES AND ENERGY CONSERVATION TO BE TESTED	
Horizontal Plane	U - Changing coverage transmittances
	α – Absorptance of Coverage
Vertical Plane	U – Changing wall transmittances
	CT – Change in thermal Capacity of Walls
	α – Absorptance of Walls
	PAFT – Change in percentage of the façades openings
	FS – Changing of Solar Glazing Factor
	VSA – Utilization Vertical Shading Angle
	HAS - Utilization Horizontal Angle of Shading

Economic analysis of the corrective measures

This step the survey was not conducted yet, work is in progress.

The economic analysis of the investment expended to implement a particular measure is what will guide us if Measures and Energy Conservation is feasible or not in the cases studied.

This step will be an analysis of the costs and effectiveness of strategies to analyze the time of return of corrective measures.

The work will take into account economic evaluations of Measures and Energy Conservation payback, complemented by the Internal Rate of Return and Cost of Conserved Energy.

DISCUSSION AND ANALYSIS OF THE RESULTS

The results of the work will be obtained along with the post-graduation course and they will be presented and defined in format of Master Thesis submitted to evaluation of the Post-Graduation Program in the Architecture and Urbanism Courses of UFPel. Up until now, 100% of the buildings downtown Pelotas was surveyed, where the research is in the simulation phase of architectural typologies.

Up until now, it is possible to observe that the percentage of 61% of typologies downtown are directed to commercial and mixed use, according to Figure 1, from these, 86% were constructed before the 1980s, according to Figure 2.

The buildings downtown are characterized by two floors in their great majority, with a percentage of 94%, according to Figure 3. But with relation to the characteristics of absorptance of the façades it is observed the predominance of light colors, where 57% of the façades have absorptance lower/equal 0.4, according to Figure 4.

It was observed that 37% of the façades shows a percentage of transparent envelopes from 30% with relation to the opaque envelope, according to Figure 5; and 78% of the buildings evaluated are located in the middle of blocks and among buildings with relation to their envelope, according to Figure 6.

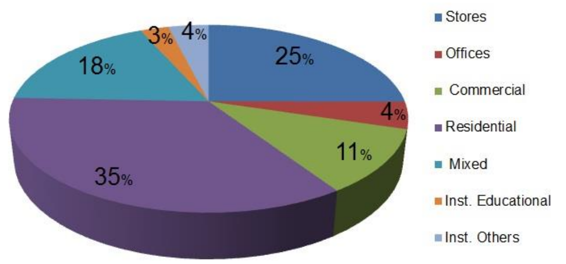

Figure 1 Functions of central typologies

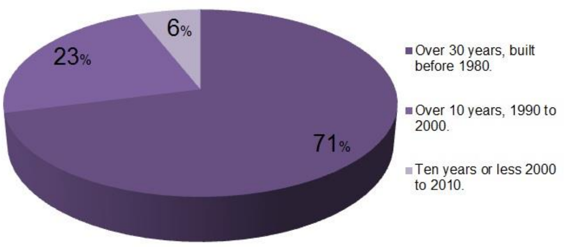

Figure 2 Age of constructions

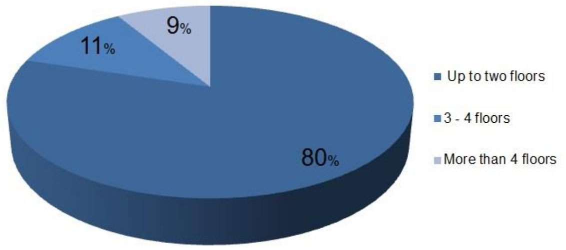

Figure 3 Height of central typologies

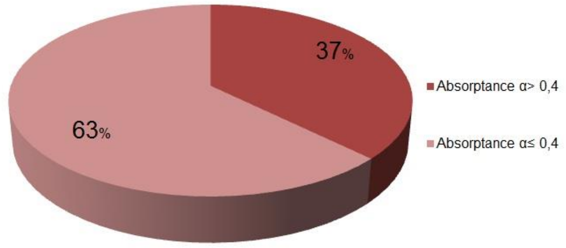

Figure 4 Percentage of the façades absorptance

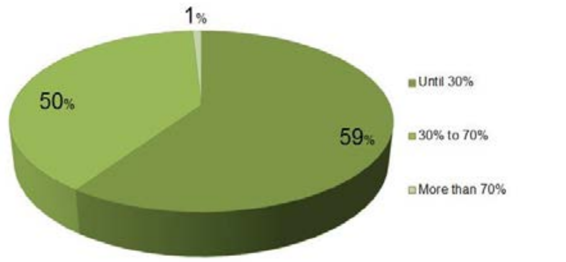

Figure 5 Percentage of transparent envelope of the façades

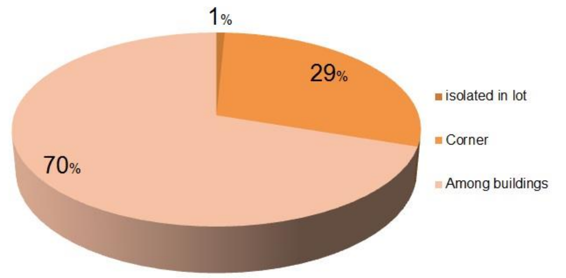

Figure 6 Position in the lot

The simulation method is indicated to allow freedom to the fulfillment of projects, in the form of the building, in the nature of their openings, solar protection as well as in the systems used; the incorporation of technological innovations, proving high levels of efficiency; use of conditioning passive strategies, making feasible non conditioning or partially conditioning buildings; incorporation of solution which are not foreseen at RTQ-C (INMETRO, 2010).

From these preliminary results, two representative types from the center of Pelotas were selected, inserted in the commercial sector, with up to two floors, one built before the 80's and the other one after that, both located between buildings and with a percentage of openings in the facades between 30% to 70%, the solar absorptance of these facades less than or equal to 0.4 characterizing light colors. In order to simulate the commercial buildings chosen, the software DesignBuilder version 2.0.3 was used. The city of Pelotas is located in bioclimatic zone 2, but as it does not have climate file yet, file TMY of Santa Maria-RS was used, which was available for the zone.

The models have been configured according to the following descriptions: Soil temperature was configured based on the instructions of the RTQ-R (INMETRO, 2010). To define the soil temperature values, software Slab was used, since it is an assistant software of EnergyPlus to calculate the soil mean temperature for each month of the year, based on the mean values of internal and external temperature of the building for the climate that will be simulated. The main façade is turned to north. The working hour is from 9 am to 7 pm from Monday to Friday and Saturdays from 9 am to 1 pm, closed on Sundays and holidays. Occupancy density is 0,15 people/m², following values set by NBR16401-3 (ABNT, 2008). The metabolic rate used for people standing, with moderate work and walking, was 93w/m², according to ISO 7730. The wearing adopted established a resistance of 0,5 clo for summer and 1,0 clo for winter, considering ISO 7730.

The buildings had been simulated as artificially conditioned, with a device type Split Air Conditioner COP 3,21 W / W (Level A). The lighting level for the environment was defined in 750lux with heat dissipation of 17w / m² NBR16401-1 (ABNT, 2008). The charge density of equipment was set to 5.4 W / m² as NBR16401-1 (ABNT, 2008). The modelling and configuration envelope typology was performed following the specific features of the building. The heating set point was set at 22 ° C and cooling set point at 28 ° C, according to NBR 16401 (ABNT, 2008).

The first store under study is an exemplar of small shop, located in the middle of the court, new, because it was built in 2007 and owned coverage exposed. The building has construction features of the first decade of this century, because it was built in 2007 for commercial use. To insert data in DesignBuilder software is necessary to transform the heterogeneous elements into homogeneous equivalent thicknesses and densities equivalent, as shown in Table 4.

Table 4
Features of the envelope building construction XXI century

ELEMENT	**e** (cm)	**ρ** (Kg/m³)	**λ** (W/m.k)	**c** (J/Kg.K)
Walls	0,12	1860	0,90	920,00
Walls plastering	0,02	2000	1,15	1000
Concrete blocks	0.10	2200	1.30	1000
Fiber cement tile	0,008	1900	0,95	840,00
Ceramic floor	0.006	1600	0.90	920
Concrete subflooring	0.15	2200	1.75	1000

The glass used in the transparent locks were simple 3mm glass, protected with aluminum blinds. The main entrance of the store is protected by an awning projection of 1.60 m. The inner part of the model was divided into zones according to the project. Figure 7 shows the 3D model of the building.

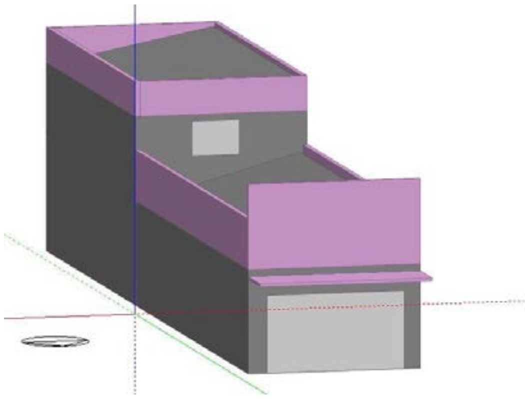

Figure 7 Building Commercial century XXI simulated

For the simulation method the building presented level E energy efficiency, thereby demonstrating that the possibility of improving the level of energy efficiency of this building, according to table 5.

Table 5
Comparison of the actual building consumption, XXI century construction, with consumption of landmark buildings. (The levels of efficiency vary from "A" to "E", where "A" is the highest index and "E" characterizing the lowest efficiency)

KWh/year	**Edificio assessed**	**A**	**B**	**C**	**D**
Equipments	14.950	14.950	14.950	14.950	14.950
Lighting	44.890	44.890	50.870	55.850	65.830
Heating	5.830	7.180	7.980	7,920	7.690
Cooling	60.900	15.570	19.580	25.140	34.430
Total	**126.570**	**82.590**	**93.380**	**103.860**	**122.900**

The second shop is an exemplary study of small shop, located in mid-block, old, was considered as conserved by keeping the percentage of the façades openings close to the original. The features of the building envelope are presented in table 6.

Table 6

Features of the envelope building construction century XX

ELEMENT	e (cm)	ρ (Kg/m³)	λ (W/m.k)	C (J/Kg.K)
External Walls	0,36	1945	0,90	920,00
Internal Walls	0,18	1945	0,90	920,00
Walls plastering	0,02	2000	1,15	1000
Concrete blocks	0.10	2200	1.30	1000
Polyvinyl chloride Ceiling	0,015	4481	0,20	-
Fiber cement tile	0,008	1900	0,95	840,00
Ceramic floor	0.006	1600	0.90	920
Concrete subflooring	0.15	2200	1.75	1000

The glass used in the transparent openings is simple 3mm, with the exception of the two vitrines that have tempered glass 10mm. Protected with aluminum shutters and wooden windows. The inner part of the model was divided into zones according to the project. Figure 8 shows the 3D model of the building.

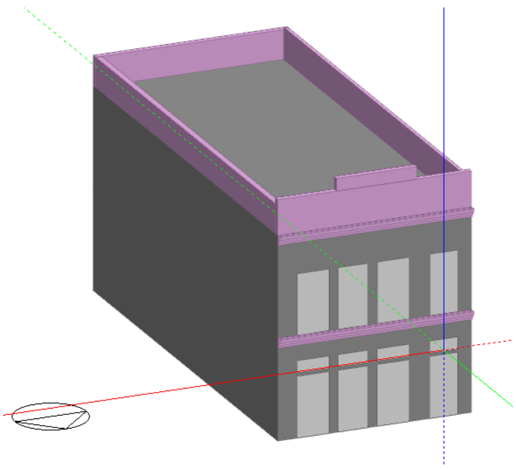

Figure 8 Building Commercial century XX simulated

Like the previous construction, it also showed level E energy efficiency, thereby also demonstrating that the possibility of improving the level of energy efficiency of this building, according to table 7.

Table 7

Comparison of the actual building consumption, XX century construction, with consumption of landmark buildings. (The levels of efficiency vary from "A" to "E", where "A" is the highest index and "E" characterizing the lowest efficiency)

KWh/year	Edificio assessed	A	B	C	D
Equipments	14.850	14.850	14.850	14.850	14.850
Lighting	44.530	44.530	50.470	55.410	65.320
Heating	7.230	12.330	13.760	12.530	12.650
Cooling	69.740	16.340	20.200	32.370	33.640
Total	**136.350**	**88.050**	**99.280**	**115.160**	**126.460**

The features of the building envelope to reach "A" level of efficiency are presented in table 8. The walls and covering show low thermal transmittance Uwall=1,00 W/(m².K), thermal Capacity of Walls 189 kJ/(m²/K) and Ucovering = 0,50 W/(m².K), thermal Capacity of covering 263 kJ/(m²/K). The solar absorptance of adopted facades less than or equal to 0,50.

Table 8

Features of the envelope building construction to reach "A" level of energy efficiency.

ELEMENT	e (cm)	ρ (Kg/m³)	λ (W/m.k)	C (J/Kg.K)
External Walls				
Plastering	0,02	2000	1,15	1,00
Polystyrene	0,024	40	0,35	1,40
ceramic brick	0,10	1600	0,90	0,92
Plastering	0,02	2000	1,15	1,00
Covering				
Plastering	0,02	2000	1,15	1,00
Polystyrene	0,06	40	0,35	1,40
Concrete subflooring	0,10	2200	1,75	1,0
Plastering	0,02	2000	1,15	1,00

CONCLUSION

When observing the data surveyed so far, it is possible to realize that significant parts of the buildings downtown Pelotas are directed to the commercial area, which is the focus of study in this paper. They follow a pattern, in their great majority, of two floors and they are implanted in lots in the middle of the blocks, becoming limited with relation to sunlight, depending on the solar position. They were built in the 1980s, have façades painted with light colors and a mean percentage of transparent envelope. Such data of the first stage of the research will help to identify the pattern of energy efficiency of commercial typologies of Pelotas.
With the results obtained from the computing simulation, it can be observed that the buildings analyzed presented energy efficiency level "E" characterizing the lowest efficiency.

Regardless of the construction techniques and materials applied in both buildings, they had low levels of energy efficiency, demonstrating that the proposed research is to identify the pattern of energy efficiency and propose measures for energy conservation, aiming to improve these levels shown to be feasible and necessary.

NOMENCLATURE

PAFT percentage of the façades openings (%);
ILD Internal Load Density (W/m²);
COP Coefficient of Performance;
VSA vertical shading angle;
HAS Horizontal angle of shading ;
U thermal transmittance (W/(m².K));
Uwall, walls thermal transmittance (W/(m².K));
Ucovering, covering thermal transmittance (W/(m².K));

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