Envelope assessment of university building on South Brazil reaching the eco-efficiency

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ABSTRACT: The performance of a building as well as the sustainability and efficiency depend on Architectural and construction factors. Considering the importance of quality of life in a building that people spend sometimes most of their time, the analysis of such elements is essential. Therefore, the research "Assessment and diagnosis of eco-efficiency on Universidade de Passo Fundo" make the evaluation about thermal and energy efficiency with building stock of the University campus. The methodology used in this work is Energy Audit, which make a relationship of the use and occupation with several types of energy. Therefore, it can be classified using two process: static data (building constructive features, interior spaces and facilities) and dynamic data, considering time modifications such as profile use, environmental variables and energy consumption. The V2 building, part of the Engineering and Architecture Faculty (FEAR), has been choose due to the different typology between other buildings inside the campus, for instance materials and construction techniques used since 2015. The installation of temperature and humidity equipment's allowed the analysis of internal environmental conditions, as a result, this data allow the analysis of building envelope, comparing it with the labelling energy efficiency in Brazil - RTQ-C, by the prescriptive method. As a result, the labelling shows that the building envelope is not satisfactory in order to achieve an ideal efficiency. The Brazilian rules stipulates minimum requirements of buildings performance besides the implementation of new guidelines according to positive applications and criteria for the buildings of Campus I.

Keywords *Sustainability on University, energy efficiency, building envelope*

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1. INTRODUCTION

Nowadays, there are a lot of worries about sustainability, including the construction and the energy efficiency in the new buildings. Climatic change caused extreme temperature ranges in different seasons of the year, demanding buildings preparation for such sudden changes. Places like universities and colleges that have studying rooms need to have some design standards accomplished to make people who use the place to feel comfortable.

According to National Energy Balance in 2013 (EPE 2014), the generation of electrical energy in public service and auto producers of Brazil reached 570.0 TWh in 2013, increasing 3.2% compared to 2012. The public service power stations with 84.8% of total generation are the mainly contributed. The major source of electric power is hydraulics, although this source reduced 5.9% compared to previous year.

The electricity generation from non-renewable sources represented 20.7% of national total, an increase comparing to 15.5% in 2012. The auto producers in 2013 represented 15.1% of total produced, considering the aggregate of all sources used.

Net imports of 39.9 TWh added to national generation, ensure an internal supply of energy power of 609.9 TWh, 2.9% more than 2012. The final consume was 516.3 TWh, an increase of 3.6% comparing to 2012. In 2013, comparing a total of 570 TWh, 48.5% (276.45TWh) of electrical energy consumption is represented by edifications, including 24.2% (137.04TWh) of total national for residential, 16.3% (92.91 TWh) for commercial and 8.0% (45.6 TWh) for public sector.

This data shows the necessity of an energy improvement in construction. A good energy efficiency is obtained by a high economy service of energy, including necessities, place, construction techniques, equipment's and systems efficiency.

According to ABESCO (Brazilian Association of Industries in Energy Conservation and Services), energy efficiency is to make more with less energy. It can be defined as an optimization of energy consumption to obtain a better result. In Brazil, as previously mentioned, there is a planning in energy sector called Energy National Plan as well as Energy Efficiency National Plan (Brasil 2011). Examples that reduce the energy necessary to attend society demands by different services: light, heat/cold, transportation, and using less energy to reduce environmental impacts.

Approximately two decades ago Brazil created National Program of Electricity Conservation (PROCEL) that help to reduce electrical fare through labelling programs for efficiency equipment`s, ensuring security to the consumer with labels marks from INMETRO – Instituto Nacional de Metrologia Normalização e Qualidade Industrial (Brasil 2001).

In 2003, it was created the National Program of Energy Efficiency in Edifications (PROCEL EDIFICA) by ELETROBRÁS, acting in civil construction and governmental, technology and economic sectors (Tubelo et al. 2013). The main goal is to promote rational use of energy consumption in edifications, conserving the use of natural resources, reducing waste and environmental impacts. The consumption of electrical energy represents 45% of edifications, reducing 50% of new edifications that are going to be part of energy efficiency.

In spite of the mostly Brazilian building regulations had a non-obliged character, according to the Regulations MPOG / SLTI nº2 (Brasil 2014), since August 2014 is mandatory the use of the label certification process in federal public buildings, in new construction or processes of retrofit, even with the development and dissemination of a manual to guide managers on procedures for obtaining labelling, according to the specific regulations.

The Brazilian regulation related to the building performance on energy efficiency started more than ten years ago (Carlo, 2008; CB3e, 2014; Lamberts, et al., 2011), although it's not

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much disseminated in the country. This research proposes a reflection about the parameters used for the V2 construction (V2 is the name adopted by the University of Passo Fundo in a reference to the building of Engineering and Architecture courses) in order to verify if the energy efficiency was achieved or not. It also intends to contribute to the improvement of a conscious design taking into account the integration of architecture and all the systems involved in the process.

2. METHOD

According to the Brazilian regulation about energy efficiency labelling - Regulamento Técnico da Qualidade do Nível de Eficiência Energética de Edifícios Comerciais, de Serviços e Públicos - RTQ-C (Brasil 2010, 2013) - the certification can be obtained in two ways. For the building design and construction, the evaluation can adopt the prescriptive method or software simulation (Lopes et al. 2011 a, b); the as-built assessment should be obtained by an in-situ evaluation, following the requisites of the normative of the evaluation of level compliance RAC-C - Regulamento de Avaliação da Conformidade do Nível de Eficiência Energética de Edifícios Comerciais, de Serviços e Públicos (Brasil 2013). The labelling considers five levels: from A, B, C, D and E (the more efficient to the less efficient, respectively).

The normative principles include three issues: the thermal performance of the building envelope; the efficiency of lighting systems and the efficiency of HVAC systems (heating, ventilation and air conditioning).

The envelope performance considers solar orientation, glass surfaces, thermal properties of materials and shadow on the façades. The lighting systems are evaluated by the installed power for artificial lighting and strategies for the use of natural light. Finally, the air conditioning systems considers performance coefficients of independent or central systems (Lopes et al. 2011 a, b).

It was chosen to analyse just the building envelope due to the fact that the air conditioning system still in installation process and as well as the lighting system, which is in complementary evaluation.

The present evaluation of the building named V2, the envelope thermal performance adopts the prescriptive method of RTQ-C (Brasil 2013). Then, the work was divided in the characterization of the building, data collection for the prescriptive method, calculation procedures and determination of the prerequisites.

The real indoor conditions were analysed through temperature and humidity measuring devices - data-loggers testo, models 175-H2 e 175-T1.

3. CASE STUDY

The University of Passo Fundo (UPF) is a multi-campus university, located in Southern Brazil; the main campus occupies a peripheral zone of the city, the building park is of around 110 thousand square metres, receiving a population of around 22.000 users (including students, teachers and staff) with several impacts on the neighbourhood context and mobility (Frandoloso & Brandli 2015).

The building study named V2: Faculty of Engineering and Architecture by the University is located in Campus I, the main campus of University of Passo Fundo, close to the Law Faculty and Technologic and the Science Park of Civil Engineer (CETEC I and II), according to Figure 1. The initial physical data characterized the area with a different construction and design typology. The building has an educational use with studying and draw rooms, living places

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and services. The construction is for Architecture and Engineer students of UPF, and is composed by three floors, of which the ground floor has 1254.18 sq. meters, the first floor has 1171.24 sq. meters and the last one has 1245.50 sq. meters, totalizing a construction area of 3670.92 sq. meters for 1135 students.

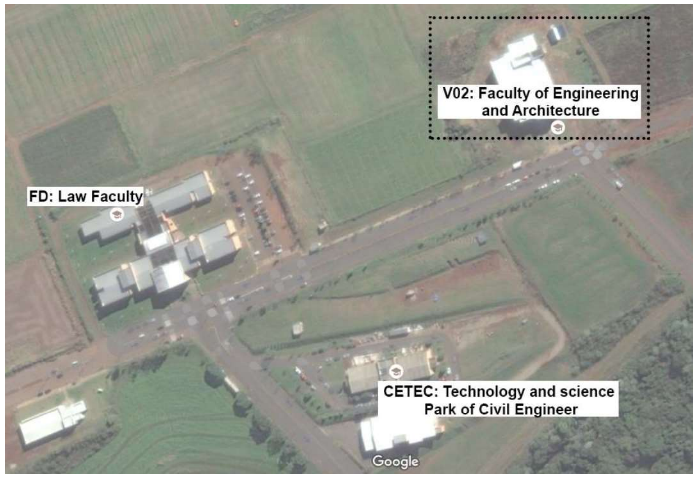

Figure 1. Sitting. Source: adapted of Google Maps, 2016.

The building was constructed between 2014 and 2015 with reinforced concrete cast on site, exterior closures in masonry brick 6 holes, internal partitions of plasterboard. The main façade is composed by aluminium composite plates (ACM) and spider glass system, showed in Figure 2. For West and East façades it was used vertical shadowing as a protection in the second and third floor.

Figure 2. Building V2. South and East Façades.

4. BUILDING EVALUATION

After getting all the necessary information about the building architecture and construction, it was identified the efficiency level acquired by the building V2 and then established normative prescriptions and partial classifications for the building envelope.

For the commercial building to be classified, the normative distributes three different percentages for each requirement, and the final classification is determined according to this percentage punctuation that varies between A (more efficiency) and E (less efficiency) presented by ENCE – National Label of Energy Conservation, see Figure 3.

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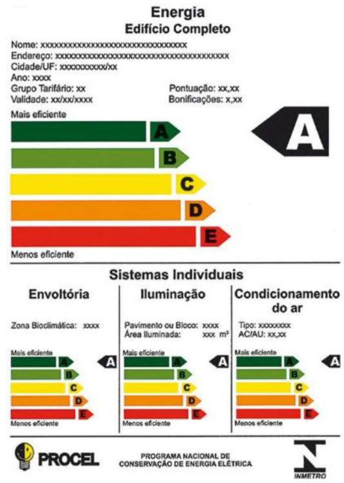

Figure 3. Energy Labeling – ENCE. Source: Brasil 2014

4.1 Data collection

Passo Fundo is located in the Bioclimatic Zone 2 according to the NBR 15220 (ABNT 2005), with warm summer and cold and humid winters. The climate data present a high thermal amplitude even in a same day; it means a complex climate to reach ideal comfort conditions. The average temperature for each season is presented in the Table 1.

Table 1: Average temperature and relative humidity. Source: PROJETEEE 2014.

Season	Temperature	Humidity
	°C	%
Summer	20.94	76.00
Autumn	24.36	77.67
Winter	14.40	78.66
Spring	19.60	73.27

To analyse and classify the building envelope, which represents 30% of general classification, composed by walls, openings and roof, it was collected physical data of the building V2, presented in Table 2, Table 3 and Table 4:

Table 2: Building Envelope

		Numerical Equivalent
AU	Useful Area (m^2)	3.670.92
Atot	Total Area (m^2)	3.670.92
Apr	Roof Projection Area (m^2)	1.357.10
Aenv	Envelope Area (m^2)	2.240,71
V tot	Building Volume (m^3)	14.572.40
PFO	Total percentage of façade opening (%)	0.19
VSA	Vertical shadowing angle	20.43
VHA	Horizontal shadowing angle	9.31
FS	Solar factor	0.87
α wall	Sola absorptance wall	0.64
α roof	Solar absorptance roof	0.25
U wall	Thermal Transmittance wall (W/m^2k)	2.4
U roof	Thermal transmittance roof (W/m^2k)	0.6
IC min	Consumption indicator minimum	24.09
IC max	Consumption indicator maximum	50.78
IC env	Building envelope consumption indicator	6.67

* considered: Bioclimatic Zone 2; Ape (projection area of the building) >500m^2

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Table 3 Building Data

Floors	Area (m^2)	Volume (m^3)
Ground	1.254.18	4.515.04
Second	1.171.24	4.216.46
Third	1.245.50	4.483.80
Roof	1.357.92	-

Table 4: Envelope Data

Façade	Area (m^2)	Opening (m^2)
West	816.85	129,46
East	659.26	97,67
North	382.69	37,57
South	381.91	153,39

4.1.1 Height Factor (HF)

The number of height factor found through the division of roof projection area and total area, showed in the Figure 4, is 0.37.

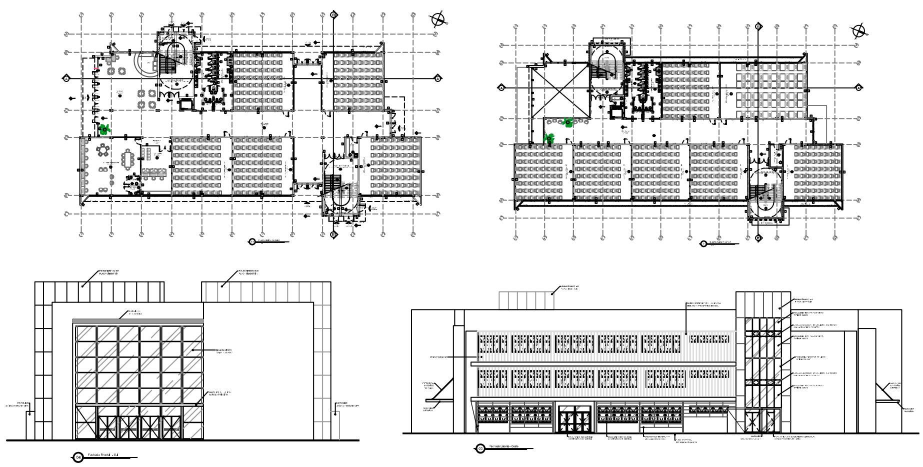

Figure 4. V2. Ground and 2nd Floor Plans; South and East Façade. Source: Setor de Projetos UPF, 2014.

4.1.2 Form Factor (FF)

Through the division of envelope area with total area, it was acquired 0,15 for the value of form factor. It is classified in two: form factor maximum for buildings with projection area less than 500 sq. meters and form factor minimum for buildings with projection area more than 500 sq. meters and it depends on the bioclimatic zone that the building is situated.

4.1.3 Total Percentage of Façade Opening (PFOt)

It represents an average value obtained through the percentage of openings in each façade. It needs to be verify through the calculation of west façade (PFOw) and if it is 20% more than PFOt, it needs to use PFOw in the equation. For the calculation of PFOt the parallel solar protection with the superior part closed in the façade needs to be disregarded. The total percentage of façade opening is 0,19%.

4.1.4 Solar Factor (FS)

The solar factor is the gain of heat and solar radiation that goes through spaces by an opening. Includes radiant heat transmitted by glass and solar radiation absorbed that is irradiated or transmitted for the space by conduction or convection processes. The solar factor considered is relative of an orthogonal solar radiation incidence in the opening.

The building V2 has transparent openings of tempered glass 10mm, then it was used FS=0.80, according to Santos & Roriz (2012).

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4.1.5 Vertical Shadowing Angle (VSA)

It is the angle formed between two different planes that have an opening base: the horizontal plane of the glass sheet base and the further extremity horizontal solar protection up to the glass sheet base; the maximum value for it is 45°.

The west and east façade's in the second and third floor have vertical shading protection, which considers zero for the angle because it can be completed closed.

In the Table 5 are being showed façade data; the global value found for the Vertical Shadowing Angle is 20.43°, according to normative equation (1).

$$VSA= \frac{(VSA_{NORTH} \text{ x } Aopening_{NORTH})+(VSA_{SOUTH} \text{ x } Aopening_{SOUTH})+(VSA_{EAST} + Aopening_{EAST})}{Atotalopening} \quad (1)$$

Table 5: Vertical shadowing angle

Façade	Opening	Angle
	m²	°
West	20.87	13 and 37
East	18.10	19 and 38
North	11.73	9 and 10
South	20.00	35

4.1.6 Horizontal Shadowing Angle (HSA)

It is represented by the angle formed between two different vertical plans: base of glass sheet and further extremity of horizontal solar protection until the base glass sheet. The maximum value of HAS is 45°.

Through the calculation of horizontal shading angle (equation 2), it is obtained 9.31°, in this way, if the value found is less than 10°, according to RTQ-C, it is used zero for HAS calculation.

$$HSA= \frac{(HSA_{WEST} \text{ x } Aopening_{WEST}) + (HSA_{EAST} \text{ x } Aopening_{EAST})}{Atotalopening} \quad (2)$$

4.2 Calculation of Consumption Indicators

For each Brazilian Bioclimatic Zone exists two equations of building envelope performance, one of it is for edifications that have projection area less than 500m². The second one is for edifications with more than 500m² for projection area. The Brazilian bioclimatic zoning is established by the norm called NBR 15220 – Part 3 (ABNT 2005). The building envelope performance is characterized by consumption indicator, that needs to be compared with a numeric scale divided in different breaks that represents one level of classification, varying from "A" (more efficiency) to "E" (less efficiency).

It was used the second equation (3) to obtain the envelope classification, according to RTQ-C (2013), due to the fact that the building V2 has more than 500m² and it is located in Bioclimatic Zone 2, according to NBR 15220 (ABNT 2005).

$$ICenv=-14{,}14.HF-113{,}94.FF+50{,}82.PFOt+4{,}86.FS-0{,}32.VSA+0{,}26.HSA-\frac{35{,}75}{FF}-0{,}54.PFOt.HSA + 277{,}98 \quad (3)$$

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where HF: height factor; FF: form factor; PFTOT: total percentage of façade opening; FS: solar factor; VSA: vertical shadowing angle; HAS: horizontal shadowing angle

For the calculation of efficiency level is used the maximum and minimum consumption level's (IC) for the building, through the equation described above, only modifying values of PAFt, SF, VSA, HAS, as presented in the Table 6 and Table 7.

Table 6. IC maximum

PFO	FS	VSA	HAS
0.60	0,61	0	0

Table 7. IC minimum

PFO	FS	VSA	HAS
0,05	0,87	0	0

The values obtained for maximum IC is 50.78 and minimum 24.09. The values obtained was considered breaks, which are divided in 4 more sub-breaks through the equation 4 bellow:

$$i = \frac{ICmax - ICmin}{4} = \frac{50.78 - 2409}{4} = 667 \quad (4)$$

Applying the equation for consumption indicator (CI) it was found 30.77. Comparing the maximum and minimum limits for each classification it gets to the final building envelope classification.

By the comparison with CI calculation and the limits presented above, it is concluded that the building V2 is classified as A.

4.3 Pre-requisites Determination

Despite of the building V2 A classification, it is necessary to verify others pre-requisites specified by walls and roof thermal transmittance, according to NBR 15220 (ABNT 2005). The parameters stipulated are showed in the Table 8.

Table 8. Envelope Requirements

Level	Thermal Transmittance		Absorptance
	Wall	Roof	
A	1.00	1.00	<0.50
B	1.00	1.50	<0.50
C and D	3.70	2.00	-

For the walls that have ceramic blocs and mortar, the thermal transmittance is 2.4(W/m^2K). The ceramic bloc with mortar, air layer, and aluminium composite plate has thermal transmittance of 1.6 W/m^2K.

The roof thermal transmittance is 0.6 W/m^2K. The comparison of the values obtained through calculations of thermal transmittance with values established from RTQ-C fits the building V2 in category C or D for walls thermal transmittance and A for roof thermal transmittance.

5. ANALYSIS AND RESULTS

The research focus on the evaluation of envelope performance due to its impact on the energy efficiency level of the HVAC system performance, in order to minimize or not the loads related to solar radiation and occupancy.

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According to prescriptive method of the RTQ-C calculations, it is concluded that the edification could have an A building envelope classification. However, analysing the thermal transmittance of walls it was realized that the use of certain materials was not enough to get the higher level of classification. In this way, the building is C and D level efficiency. The coverage has A classification due to the use of better materials and insulation materials such as extruded polystyrene foam and air layer. As a general result, the building was classified as C and D for envelope performance.

As mentioned, the HVAC is yet in installation and connection to the power grid process, and the lighting system was analysed in another research field. Obviously, when all the three aspects are ready (envelope, lighting, and especially HVAC) the assessment will be integrated, in order to present the complete level of the building energy efficiency.

Comparing the envelope performance with the indoor temperature and relative humidity, measured using Testo® data-loggers, the labelling corresponds to the environmental conditions. The data presented on Table 9 indicates that the thermal insulation of walls and roof allow a great heat gains in hot periods, also heat loss in the cold season, in order to corresponds to the wide temperature range. It means that the building envelope influences in an inadequate heat balance. In the operation of HVAC, its load performance will suffer direct influence and, consequently, it will consume more energy than an ideal eco-efficient building.

Table 9 Indoor conditions (08/03/2016 – 31/05/2016)

Room	Solar Orientation	Indoor conditions	Min.	Max.	Average
204	East	RH (%)	53,20	99,90	79,91
		Temp (°C)	11,30	30,00	20,81
304	East	Temp (°C)	12,30	29,80	20,44

6. CONCLUSION

The evaluations took into consideration only the aspects connected to the building envelope, which achieved the level A of classification for the coverage and C and D for the remainder. Levels C and D are a consequence of the walls' transmittance that did not achieve desirable performance in order to reach a higher level of classification.

This paper demonstrates that the decisions made during the design phase, as well as the materials and techniques used in the construction of the building V2 will serve as the basis for the decisions that will be taken for the construction of others buildings, which are part of a complex of 5 buildings that makes up the Faculty of Architecture and Engineering (FEAR). This analysis is of extreme importance to obtaining further constructive guidelines, aimed at energy efficiency and sustainability in the campus.

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