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## THE INFLUENCE OF BUILDING ENVELOPE ON ITS ENERGETIC EFFICIENCY

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**Abstract.** *The energetic efficiency in buildings is getting more and more space and importance on construction sector. With the objective of evaluating the behavior of different envelope systems of a house on constructive systems such as light steel frame, wood frame and conventional construction system, were specified some models to be simulated on the software Energy Plus. Because of the importance of climate features of the local where the house is and its influence on the envelope systems' behavior, the study was limited to the three bioclimatic zones there are on the state of Rio Grande do Sul. Results related to envelope systems that have insulation material on its composition showed better energetic efficiency, such as the envelopes of wood frame construction system, which used wood siding on the exterior side of the wall. On the other hand, the envelopes of conventional construction system didn't performed good results about energetic efficiency when compared to the results obtained when using envelopes of the constructive systems light steel frame and wood frame. The envelope that has brick and stucco in both sides of the wall was classified the worst envelope system in relation to energetic efficiency.*

**Keywords:** *Energetic efficiency, Envelope systems, Thermal performance.*

### 1. INTRODUCTION

According to the World Business Council for Sustainable Development (WBCSD) (2007), in most countries the buildings represent an energetic consumption around 40% of the total energy used up in a country. That's why it is necessary to have dedication in order to reduce the energetic consumption of the buildings to positively contribute on the energy use and also on climate change.

The constant emphasis on the relevance of sustainable development has led to changes in the construction industry in recent years, to which new concepts, tools and materials integrated in order to achieve the new perspectives of the civil construction sector. (AGOPYAN, JOHN, 2011).

Light steel frame and wood frame construction systems have been in constant development in Brazil with the proposal of sustainable systems, standing up for the concept that the performance of the envelope systems provides better energy efficiency and thermal comfort than the envelope used in conventional construction. (LP, 2012).

Due to the changes that the construction industry has been experiencing in order to achieve sustainable development, as accounted by Agopyan and John (2011) and the highlight of WBCSD (2007) about the importance of energy efficiency in buildings, it can be deduced that there is a trend on looking for projects and materials that have good performance about energy efficiency and thermal comfort simultaneously. Therefore, the knowledge of the results about the behavior of the thermal exchange of envelope systems throughout the project's life allows incorporating the concept of energy efficiency to the buildings from the choice of the envelope system to use in the building.

This study come up with the analysis and comparison of data related to energy efficiency results associated to the envelope systems. The envelope systems considered in the study are the main ones that constitute light steel frame, wood frame and conventional constructive systems, from which the results obtained and the most significant differences were analyzed and compared.

To obtain the results, simulations were performed in order to determine the energy efficiency of a standard residential project in relation to the different types of envelope. For the simulations, Energy Plus software was used. It is worth highlight that the project itself has not been evaluated, but the influence that the choice of the envelope system

has on it about the necessary energy spent with heating and cooling in order to maintain the thermal comfort in the residence.

As the climatic features are an influent aspect for the analysis of the energy balance of the buildings, in order to limit the research, the envelope systems were analyzed for the state of Rio Grande Sul, embracing the three bioclimatic zones that integrate it, according to NBR 15220 (Brazilian Association of Technical Standards (ABNT), 2003). The referential cities for the simulations were Bento Gonçalves (zone 1), Santa Maria (zone 2) and Porto Alegre (zone 3).

## **2. BIBLIOGRAPHIC REFERENCE**

### **2.1 Energetic Efficiency on Buildings**

According to Ferrer and Garrido (2013), the energy efficiency in buildings is about the use of strategies and adaptations in the projects, in order to consider the features of the environment in which the building is inserted, with the purpose of reducing the energy consumption of the building and consequently to reduce the carbon dioxide and pollutants emission into the atmosphere. Also, due to economic and population development, energy consumption tends to grow constantly (especially in developing countries), and for that reason, mitigating measures must be adopted.

Isolani (2008) claims that investing in strategies that result in energy savings is the first available source of energy. According to WBCSD (2007), buildings are responsible for a significant part of energy demand, and intervention in it can contribute to the reversal of this situation, since technologies and knowledge are already available to reach considerable energy efficiency levels, which positively influences on the reduction of energy consumption, as well as on the issue of thermal comfort.

The search for energy efficient buildings is related to maintaining thermal comfort in order to use the less possible of conventional heating or cooling systems. However, with the use of conventional materials, the level of thermal comfort admitted by the user is not reached, and the use of such systems is required. Still, if the project is developed with the care of reducing energy demand, the decrease in consumption is significant compared to conventional buildings that do not incorporate energy efficiency strategies. (FERRER, GARRIDO, 2013).

According to Ganhão (2011), the use of passive solutions supported, if necessary, with active solutions is able to achieve the results that join both the improvement of the energy performance of the building and the thermal behavior.

For the elaboration and construction of the project of a building that has in view the energy performance and thermal comfort, when integrating the passive elements it is important to consider the local climatological data, as well as its effects on the thermodynamic behavior of the system. Any building is able to keep constantly changing mass and energy with the environment in which it is inserted. This characteristic fits the buildings as an open thermodynamic system of transient regime that responds to the effects of conduction, convection and radiation. (FERRER, GARRIDO, 2013).

According to Carlo (2008), the heat transfer that occurs through the envelope of the building is directly connected to the energy consumption, and this subject must be studied and treated with importance in energy efficiency programs in buildings, from the project until the construction. Characteristics such as the thermal properties of the material, color, and the conditions of the environment where the building is inserted influence the behavior of heat transfer through the building envelope materials.

The materials have different heat transfer coefficients, and therefore have specific thermal conductivity values, which represent the capacity of a material to conduct heat. In this analysis, the thickness of the material and the temperature difference in the areas where the heat exchange is occurring are also taken into account. (FERRER, GARRIDO, 2013).

In general, all the opaque envelopes of a building are protagonists of the phenomenon of heat transfer by conduction. However, according to Ferrer and Garrido (2013), the amount of energy transmitted depends fundamentally on unique characteristics of the materials, such as conductivity, density and heat capacity. The effect of incident radiation is also relevant for the transfer of heat through opaque envelopes, which is divided into two parts: the reflected radiation, which does not change, and absorbed, which is transformed into thermal energy. (LAMBERTS et al., 2016).

On the other hand, the translucent envelopes have similar behavior to the opaque ones about heat transfer. The difference is that in relation to the incident radiation, in addition to the absorbed and reflected parcels, there is a portion that is directly transmitted into the interior of the building. The determination of the fractions related to such portions of radiation is complex. The thermal changes through translucent envelopes occur faster, therefore it is relevant to analyze alternatives of these kind of elements, looking for the ones that have less impact, such as the analysis of the best type of glass or the use of sunscreens in openings. (LAMBERTS; DUTRA; PEREIRA, 2014).

Insulating materials are known by its high porosity. The filling of these voids is done by air (without movement), which makes them materials of excellent resistance to heat transfer. (HINRICHS, KLEINBACH, REIS, 2013). According to Isaia (2010), the thermal flow that occurs by conduction, when reaching the voids, reduces significantly once it depends on the convection phenomenon to give continuity to the thermal flow, which hardly occurs with confined air, as is occurs in this case.

A strategy frequently used to reduce heat transfer is the application of air chamber, in which only the phenomena of convection and radiation occur, excluding the portion of heat transfer through the conduction. A better result can be

obtained when applying an insulating material in the space of the air chamber, increasing significantly the thermal resistance of the surface in question. (LAMBERTS, DUTRA and PEREIRA, 2014).

## 2.2 Computacional Simulation Using the Software Energy Plus

The energy analysis of a building is of great complexity, and can be evaluated basically through monitoring or simulation. The monitoring consists of the collection and analysis of the physical results of a building, while the simulation uses the previous analysis of the thermal behavior of the building. The simulation allows analyzing how a certain building behaves thermally under specific climatic conditions. It is a strong project support once it allows analyzing different strategies for a problem in order to improve energy efficiency. (FERRER, GARRIDO, 2013).

Crawley et al. (1999) highlights that EnergyPlus is a building simulation program, originated from two software developed by the US government (DOE-2 and BLAST). The Energy Plus comes as a new tool, which adds the best features of the old programs, as well as new features and assignments. One of the main priorities sought in the program was the integration of analysis. The simulation based on the energy balance of the building exposed to a specific location with specific thermal characteristics, it is calculated the cooling and heating need to each short period of time (which can be determined with input data) and the building's response to energy consumption.

The Energy Plus tool is used to obtain energy efficiency results, mainly in the matter of comparing results from the use of different strategies in the search for the reduction of energy consumption. It can be noted from the study of Cavalcante (2010), who made use of the Energy Plus software for obtaining results about the energy performance of artificially conditioned offices as the variation of the envelope applied in the building. In addition to Cavalcante (2010), Carlo (2008) used the software to analyze the energy performance of prototypes of institutional and commercial buildings with focus on the envelope, and Ganhão (2011) that by analyzing the results obtained from Energy Plus evaluates the improvement of the energy performance of a building from the adoption of active and passive strategies.

## 2.3 Constructive Systems: Light Steel Frame, Wood Frame e Conventional

The economic conditions of Brazil and the availability of materials drive civil construction into the application and development of reinforced concrete technology (material composed of cement, aggregates, water and steel), widely applied in buildings. (LOTURCO, 2008). Brickwork is used in most of the buildings that have reticulated reinforced concrete structure (conventional constructional system). Characterized as having no resistance to actions, brickwork protects and compartmentalizes the building. (SILVA; GONÇALVES and ALVARENGA, 2006).

As a finishing of the brickwork surface, the coating mortar is used, which will be the base for the final finishing, such as painting or application of ceramic coating. According to the Brazilian Association of Portland Cement (ABCP) (2002), the mortar coating is the composition of one or more layers superimposed uniformly with the main function of protecting the substrate from the action of aggressive agents and provide tightness. It also has important participation in the thermal and acoustic insulation of the brickwork.

The light steel frame and wood frame construction systems, consist of reticulated panels formed by wood frame or steel frame, to which OSB boards are applied, thermal and acoustic insulation in the middle of the panel and a versatility of coating elements, such as cement boards, gypsum boards, vinyl siding and smart side or wooden boards. (LP, 2012). The method of construction of these systems supports the idea that the thermal performance and the energy saving from the use of these constructive systems is significant both during the execution and during the time of use of the building. The relationship with sustainability of this constructive system is about issues like the low emission of carbon dioxide, reduction in water consumption and the generation of waste and application of materials that can be reused. (LP, 2012).

## 3. METODOLOGY

In order to evaluate the energetic performance of different envelopes of the light steel frame, wood frame and conventional systems, Energy Plus simulation software was used.

It was defined a standard residential project with 69.35 square meters, which is composed of kitchen, living room and integrated dining room (social area), three bedrooms, bathroom, service area and circulation. The choice of this project to carry out the simulations was made because it was one of the most prominent standard projects of a construction company that gave in the use of its project files to carry out the study.

The establishment of the solar orientation was defined as having the main frontage to the north, since the study is about the behavior of the envelopes in the state of Rio Grande do Sul, being in this region, the north the most valued solar orientation. This pattern was maintained in all analyzes, and it is valid to highlight that the solar orientation was not considered as a study parameter in this work, but as a standard aspect for the analysis of variation of the behavior of the envelopes.

Among other standard aspects that have been defined, there are the number of people who live in the house and the power of electrical equipment and lamps. These definitions were based on a single-family residence in which each

dormitory is occupied by two persons. For each item, a schedule was specified according to the type of activities of the occupants and the fraction of use of the equipment and lamps, respectively, according to the occupation periods of the residence. In the case of air exchange, it was considered one air exchange per hour for all rooms in the residence and five exchanges per hour in the attic.

As required by Energy Plus, the thermal zones of the project must be defined. For this, it was determined that each room of the residence constitutes a distinct thermal zone, delimited by the walls.

In order to obtain results about the annual energy consumption of the building looking for the longest possible period of thermal comfort during the occupation of the residence, it was considered the use of HVAC (heating, ventilation and air conditioning) equipment of the type PTHP (packaged terminal heat pumps), which can be used for heating and cooling environments in residential projects. Therefore, for the thermal zones that characterize environments of longer permanence and social conviviality, case of the social area and of the three bedrooms, it was admitted an air conditioning equipment unit for each zone. The other areas of the building were dispensed from the use of an active strategy to assure the temperature of thermal comfort during occupancy.

The main analyzes to be studied are related to the total energy expenditure of heating and cooling of the residence during the period of one year. Therefore, it was necessary to establish a schedule of occupancy of the residence environments, adequate to establish the condition of use of the equipment for heating and cooling in the thermal zones in order to reach specific temperature.

The thermal zone of the social area had an established occupation schedule different from the schedule of occupancy specified for the bedrooms. The definition of these occupation schedules was based on the routine of a single-family residence in which all occupants work during the day and return to the residence in the evening during the week, and remain longer periods at home on the weekends and holidays. It was considered that whenever there was occupation in the thermal zones, the air conditioning equipment should be turned on when the temperature was not between the cooling and heating setpoints.

The air temperatures that defined the thermal comfort interval were specified as being 21 °C (heating setpoint) and 24 °C (cooling setpoint). When the air temperature was within this range, it was not necessary to turn on the equipment, otherwise, air conditioning equipment was required until the temperature was reached within the setpoints.

For the analysis of the behavior of the walls of building envelopes, some constructive aspects were standardized, as is the case of the roof, openings and ceiling, as presented in Table 1. These elements were not modified, and for each simulation, only the envelope system of the exterior walls and the climatic archives of the reference cities were changed in order to obtain results to evaluate the behavior of the envelope systems among each other, and in each bioclimatic zone of Rio Grande do Sul.

Table 1. Standardized constructive elements

Roof	OSB board + asphalt shingle
Ceiling	Insulation wool + gypsum board
Floor	ceramic coating
Openings	Wood
Glass	Simple glass 3mm

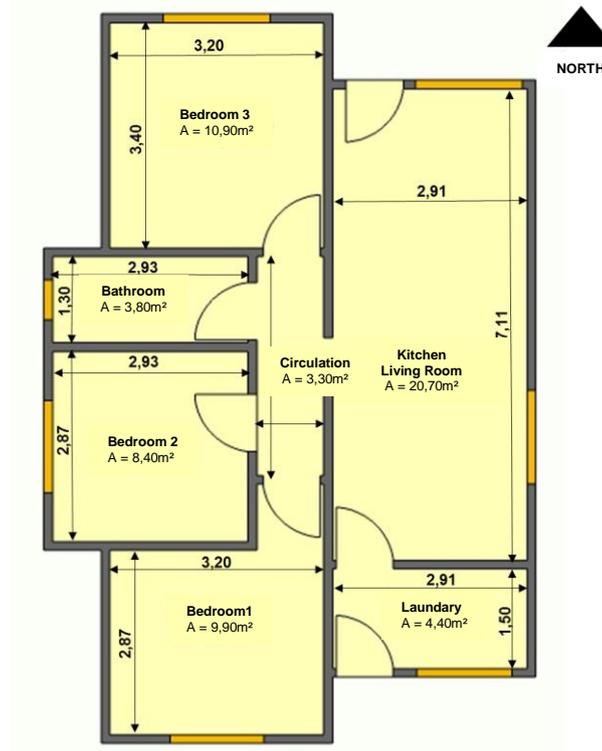


Figure 1. Residential project used for the simulations

The types of envelope systems were determined according to the most frequently used in the execution of buildings, according to information from a construction company specializing in the construction of residential buildings in light steel frame, wood frame and conventional systems. Table 2 lists the names of the envelop system as well as their composition and the final wall thickness.

Table 2. Composition of the envelope systems

REFERENCE	ENVELOPE SYSTEM COMPOSITION (from the exterior material to the interior material)	THICKNESS (mm)
A	Hollow backed vinyl siding + OSB + air space (light steel frame panels) + insulation + gypsum board	116.6
B	Hollow backed siding + OSB + air space (light steel frame panels) + insulation + OSB + gypsum board	127.7
C	Siding hardboard + OSB + air space (light steel frame panels) + insulation + gypsum board	123.1
D	Siding hardboard + air space (light steel frame panels) + insulation + gypsum board	112
E	Cement board + air space (light steel frame panels) + insulation + gypsum board	112.5
F	Cement board + OSB + air space (light steel frame panels) + insulation + gypsum board	123.6
G	Wood siding + air space (wood frame panels) + insulation + gypsum board	122.5
H	Wood siding + OSB + air space (wood frame panels) + insulation + OSB + gypsum board	144.7
I	Wood siding + air space (wood frame panels) + insulation + OSB + gypsum board	133.6
J	Stucco + concrete block + stucco	250
K	Stucco + brick + air space + brick + stucco	300
L	Stucco + brick + stucco	150

- Envelopes of light steel frame constructive system
- Envelopes of wood frame constructive system
- Envelopes of conventional constructive system

The internal partitions of each envelope were defined as follow: for the envelopes of wood frame (G to I) and light steel frame (A to F) constructive system the internal partitions were composed of gypsum board, insulation, air space (panels) and gypsum board. The internal partitions used in the case of envelopes of conventional building system (J to L) were composed of the respective materials of the envelope system in each situation, and for K, it was not considered an air chamber in the composition of the internal partitions.

The thermal properties of the building materials that constitute the envelope systems and the other constructive elements were obtained from the software database, which includes the characteristics of the main materials of the construction systems considered in the study.

It is known that a factor of strong influence in the energy efficiency is the climatic conditions of the environment where the building is inserted. Therefore it is relevant the determination of the climatic features of the area in which the study will be applied. Considering NBR 15220 (ABNT, 2003), it is remarkable that the state comprises three distinct bioclimatic zones (Z1, Z2 and Z3), for which the behavior of the envelope systems will be evaluated. In order to perform the analysis, a reference city was defined for each bioclimatic zone: Bento Gonçalves (Z1), Santa Maria (Z2) and Porto Alegre (Z3). For the simulations, it was used the climatic files of each reference city, obtained from the data of National Institute of Meteorology (INMET), which is available on the site of the Laboratory of Energy Efficiency in Buildings (Labee).

After defined the project, all the fixed parameters, the envelope systems to be evaluated and the cities of application, it was possible to begin the simulation. The results were obtained about the annual energy demand and the monthly behavior in relation to the energy demand heating and cooling related to the envelope systems that have been highlighted as the worst and best situations taking into consideration the energy efficiency of the building.

#### 4. RESULTS

Once the study of energy efficiency is the objective of this research, the analysis of the energy spent of the residence along one year allows to notice the behavior of the building as the envelope system that composes it is changed.

It is worth mentioning that the only change made in each simulation was the composition of the envelope. All other parameters were fixed and the air conditioning equipment was automatically sized by the Energy Plus software as the need of each situation to maintain the temperature range as defined by the setpoints.

Table 3, Graphics 1, and 2 introduce a summary of the results of the simulations performed considering the climatic characteristics of the city of Porto Alegre, which represents the bioclimatic zone 3.

Tabela 3. Total, heating and cooling energetic spent for the city Porto Alegre (zone 3)

ENVELOPE REFERENCE	TOTAL ENERGETIC SPENT (kWh)	HEATING ENERGETIC SPENT (kWh)	COOLING ENERGETIC SPENT (kWh)	COOLING AND HEATING ENERGETIC SPENT (kWh)	
A	5010.82	1093.86	1113.91	2207.77	44%
B	4976.26	1058.91	1121.26	2180.17	44%
C	5008.51	1092.38	1113.4	2205.78	44%
D	5022.91	1115.94	1100.7	2216.64	44%
E	5046.61	1114.15	1124.38	2238.53	44%
F	5025.53	1093.23	1127.89	2221.12	44%
G	5000.93	1086.62	1112.66	2199.28	44%
H	4927.96	1025.19	1114.49	2139.68	43%
I	4966.37	1052.58	1119.1	2171.68	44%
J	5402.83	1306.94	1298.85	2605.79	48%
K	5012.91	1173.36	1092.16	2265.52	45%
L	5573.08	1390.55	1364.98	2755.53	49%

 Envelopes of light steel frame constructive system

 Envelopes of wood frame constructive system

 Envelopes of conventional constructive system

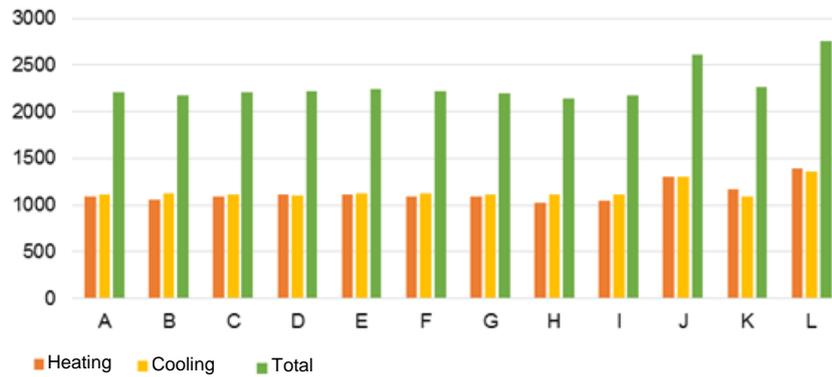


Figure 2. Graphic of cooling and heating energetic spent for the city of Porto Alegre (zone 3)

Analyzing Graphic 1 and Graphic 3 of the city of Porto Alegre, it can be seen that the total demand for heating and cooling is practically the same throughout the year, with energy costs with heating representing on average 22% of energy total expenditure, while cooling costs, 23% of the total.

It is also observed that the total energy expenditure with heating and cooling represents on average 45% of the energy expenditure of the building. However, if we compare the percentage related to energy expenditure with heating and cooling of the building when the envelopes are in the wood frame system and light steel frame, an expense equivalent to 44% of the total is observed, whereas this percentage is 48 % in the case of envelopes of Brazilian conventional construction system.

It can also be seen that the J and L envelopes, which are in the conventional system, differ in relation to those in the wood frame system and light steel frame, and are the envelopes associated with higher energy costs with heating and cooling (48% and 49% of total energy expenditure, respectively).

On the other hand, the three envelopes associated with lower energy costs with heating and cooling are H, I and B (43%, 44% and 44% of total energy expenditure, respectively), referring to the wood frame construction system (H and I) and light steel frame (B).

The energy expenditure with heating and cooling when using the envelope H represents an energy saving of approximately 22.3% id compared to the envelope L, and of 17.9% if compared to the envelope J.

In the case of the use of envelope B, this economy represents 20.9% if compared to the envelope L, and 16.3% when compared to the envelope J.

When looking at Graphs 2 and 3, which represent the behavior of the envelope systems J, L, B and H throughout the year, it is noticed that the behavior about the need for heating and cooling is exactly the same, despite the difference with the energy expenditure.

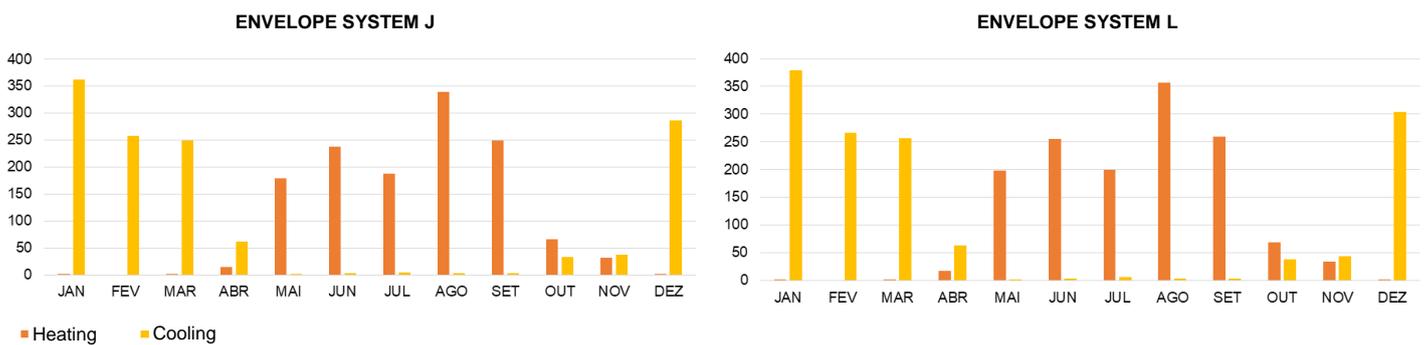


Figure 3. Graphic of the behavior of the envelope systems J and L in the city Porto Alegre throughout one year (kWh/month)

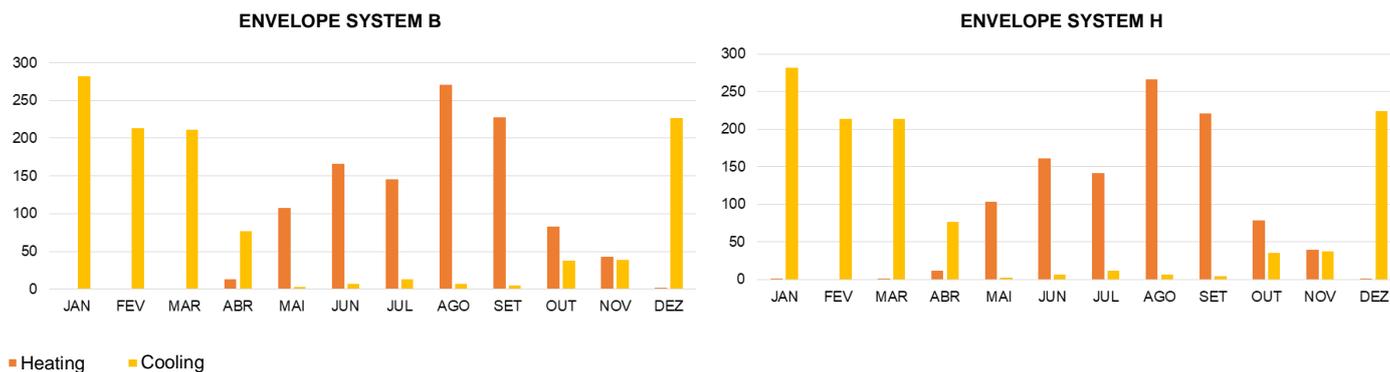


Figure 4. Graphic of behavior of the envelope systems B and H in the city Porto Alegre throughout one year (kWh/month)

It can be seen that in the case of envelope systems B and H, the energy expenditure with heating and cooling is lower in the months when the need for heating or cooling is higher. However, in months characterized by higher temperature variation, in the case of the months of April and October, it is observed a better performance of J and L envelopes, which can be explained by the phenomenon of thermal inertia that heavy material such as stones and bricks have and so, are capable to save thermal energy and use it when necessary.

The same analyzes about the energy expenditure of different envelopes were made for the cities of Santa Maria and Bento Gonçalves, representatives of zones 2 and 1, respectively.

Unlike Porto Alegre, in the case of the city of Santa Maria, there is a greater demand for heating (which represents around 29% of the total energy expenditure) than for cooling (approximately 20% of the total energy expenditure). The energy spent on heating and cooling is the most significant part of the total energy demand of the building.

The average energy expenditure of heating and cooling of the residence represents 48% of the total expenditure. In the case of constructive systems wood frame and light steel frame the demand with energy expenditure for this purpose is 47% and in the case of composition of envelopes of conventional Brazilian constructive system, the energy expenditure with heating and cooling is on average 51%.

In the same way of Porto Alegre, it is visible that the energy expenditure of the J and L envelopes, referring to the Brazilian conventional construction system, stand out for the higher consumption. The energy expenditure with heating and cooling represents more than half of the total energy expenditure of the building (51% and 52%, respectively). Regarding the envelopes with the lowest energy expenditure, H, I and B stand out, as in the case of Porto Alegre. These envelopes, which represent the envelopes of the wood frame and light steel frame construction systems, represent energy costs with heating and cooling equivalent to 47%.

The H envelope, associated to the lower energy expenditure with heating and cooling, represents an economy of 20.6% if compares to the envelope system associated to the higher energy expenditure (L). It also have an economy of 16.2% in relation to the envelope J. The use of envelope system B in the building implies a saving of 19.2% in the energy expenditure with heating and cooling if compared to the L envelope and an economy of 14.7% in relation to the envelope J.

When observing the envelopes behavior throughout a year in relation to the energy expenditure with heating and cooling associated to the use of the envelopes J, L, B and H, it is notable that, for Santa Maria city, the behavior does not remain constant in all situations, whereas for April the demand reversal when the envelope systems are compared. While for J and L the higher demand is for heating, for B and H, the higher demand is for cooling. It is also noticed that in the months of constant temperatures, the envelopes B and H represent a better energy efficiency once they result in a lower energy expenditure (the difference is more significant when the need is for heating). On the other hand, it is noticed that in months of considerable thermal variations (where both heating and cooling are required) the J and L envelopes perform very similarly, and in some cases, even better when compared to B and H about the energy demand for heating and cooling.

In the case of Bento Gonçalves, the disparity of energy expenditure with heating in relation to the expenditure with cooling becomes evident, as it is noticed that the energy demand for such purposes is significant in relation to the total energy expenditure, as well as it was observed in the case of Santa Maria. However, for the city of Bento Gonçalves, this difference is more significant, with heating expenditure accounting for about 36% of total energy expenditure, while cooling represents only 9%.

The average energy expenditure with heating and cooling of the building in the city of Bento Gonçalves is equivalent to 45% of the total energy expenditure. However, if we evaluate only the cases of envelopes of wood frame and light steel frame construction systems, this portion is approximately 44%, while for the conventional construction system, around 49%.

As observed in other cities, the J and L envelopes, which are envelopes of the conventional construction system, stand out for the higher energy expenditure with heating and cooling, equivalent to 49% and 51%, respectively. In the same way, the envelopes associated to the lower energy costs are the same ones observed in cities Porto Alegre and Santa Maria: H, I and B, referring to the construction systems wood frame and light steel frame. The expenditure of the building with heating and cooling in relation to the total energy expenditure is 43% for the H envelope and 44% for the I and B.

The use of the envelope H in the building represents an economy of 25.9% if compared to the envelope L, and of 21.1% if compared to the envelope J. If applying the envelope system B in the building, it represents an economy of 24.0% if compared to the L envelope, and 19.1% if compared to the use of the J envelope.

When comparing the results regarding the energy expenditure of the enclosures J, L, B and H for the city of Bento Gonçalves, a standard behavior about the demand of heating and cooling during the year is noticed, except about the amount of energy necessary.

As the climatic features of this city predominate the demand for heating, the difference of energy expenditure between the envelopes J, L and B, H is even more significant when compared to the other cities. It is also clear that the difference in total air conditioning expenditure is directly related to the demand for heating. The energy expenditure is reduced in the case of the use of envelope systems B and H. Similarly, in April, for example, where there are variations in temperature and considerable demand for both heating and cooling, the demand for cooling when using the enclosures B and H is considerably higher if compared to the demand for cooling when the envelopes J and L are applied to the building.

## 5. CONCLUSION

The energy expenditure of the building with heating and cooling in the three study cities represents a share equivalent to almost 50% of the total energy expenditure of the residence, which highlights the importance of the search for means that generate energy savings, and consequently, better energy efficiency in buildings.

When comparing the cities studied, it is clear that the energy expenditure with heating and cooling is higher in Santa Maria and Porto Alegre and lower in Bento Gonçalves. Porto Alegre and Santa Maria have considerable thermal variation, since the expenses with heating and with cooling are similar. On the other hand, Bento Gonçalves, which has the lowest energy expenditure with air conditioning, presents a significantly higher demand for heating and low demand for cooling.

In general, the total energy spent of the buildings is directly related to the total energy expenditure with heating and cooling, and represent the largest constituent part of the energy demand of the residence.

The most relevant envelopes of the study, associated with the smaller and the higher energy costs with heating and cooling of the building are the same for the three cities: B, H and I associated to the lower energy costs, and J and L associated to the higher energy demands.

Envelope systems B, H and I, in all cases, perform better when climatic conditions require only heating or cooling. On the other hand, generally in periods when there are constant heating and cooling demands (in cases of frequent thermal variations), envelopes B, H and I have a performance very similar or inferior to J and L.

H and I are envelopes of wood frame construction system and B of the light steel frame construction system. All are characterized by having insulation materials in their composition, as is the case of PET wool, and the air chamber. In addition, OSB boards are used in the case of the three envelopes, and wooden walls in H and I. According to Mady (2008), the cellulosic composition and the cellular structure of the wood, which consists of pores with trapped air, characterizes the low thermal conductivity of this natural material and the performance as an insulator.

The heat transfer resistance, characterized by the insulating materials, explains the best energy efficiency when applying the B, H and I envelopes in situations of demands for heating, when it is necessary to maintain the internal temperature, with low losses to the external environment. On the other hand, the envelopes J and L, which are composed of concrete blocks and bricks, respectively, have the property of thermal inertia. According to Lamberts, Dutra and Pereira (2014), it is an interesting property when there are temperature variations, so that the heat retained by the material due to its thermal inertia can be gradually returned to the internal environment in case of temperature drop, acting as a source of thermal reserve.

Regarding the energy savings, comparing the lower and higher energetic expenditure with air conditioning, it is noticed that the most demand for heating there is, most significantly is the economy with the energy expenditure if using envelope systems composed with insulating materials. This is the case of Bento Gonçalves, which has the largest economy if compared to Santa Maria and Porto Alegre.

Therefore for the bioclimatic zones of Rio Grande do Sul (a region where climatic features end up with energy expenditure with heating between 22% and 36% of the total energy spent of a building), the wood frame and light steel frame constructive systems, due to the characteristics of their envelopes (which integrate thermal insulation), condition better energy efficiency for homes.

## 6. REFERENCES

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