ENERGY BEHAVIOR IN LOW-INCOME HOUSING IN VERY COLD CLIMATES. THE CASE OF THE PROVINCE OF TIERRA DEL FUEGO, ARGENTINA.

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ABSTRACT

This paper analyses the current state of the energy consumption in public housing built during the last few years in the province of Tierra del Fuego. A synthesis of the results obtained from the analysis of various housing with typological and constructive differences is presented; as well as a comparison with dwellings in other localities of the country with similar characteristics. Different typologies are compared, grouping them under the same heating degree-day for their comparison and there arises as a hypothesis that the housing in the south extreme of the Patagonia has a high energy consumption that exceeds the variables of the construction and the project. The results are systematized in order to serve as a useful precedent for future improvements. The feasibility of their implementation and the contribution to investigation and development in the sector are discussed as well.

INTRODUCTION

The policies of the *Instituto Provincial de la Vivienda* (Province Housing Institute) of the province of Tierra del Fuego has provided since its creation -end of the 70s beginning of the 80s- a great diversity of solutions to the housing needs, both architecturally and as regards construction.

Currently, The Housing Federal Program I and II are being carried out. They are national programs for the construction of 120.000 dwellings, of which the province of Tierra del Fuego will receive 2200 units from the first program and 2800 from the second federal program. These dwellings will be able to accommodate approximately more than 20.000 people (Figure 1). The city of Río Grande will be in charge of the construction of 10017 units, the city of Tolhuin will be constructing 47 and the city of Ushuaia 248, this distribution corresponds to the first project that started in 2004 and is due to finish in 2008. As regards the second program, the entity that is in charge of the project, the execution and the planification has not yet determined the corresponding housing distribution for each city.

As regards our case study, the housing estate of the province of Tierra del Fuego differentiates itself from that of the other provinces in that it has a high percentage of public housing; to be more specific, of the total population (101.079 inhabitants according to the last survey of the INDEC, 2001, and according to the information provided by the Ministry of Federal Plannification, Public Investments and Services, The Public Building Secretary and the Undersecretary of Human Development and Housing), in the province 65 %[1] of the population live in this kind of housing, therefore we can appreciate the impact that the different operations have on our study environment.

Figure 1: Prov. location Tierra del Fuego in the Rep. Argentina. Location of Río Grande.

The general aim of this paper is the comparative analysis of the energy used in houses of four different Argentinean cities, focusing more specifically on the energy consumption in public dwellings built by the Govenment of the city of Rio Grande, Tierra del Fuego. The results of the thermal behavior of the 20 cases analyzed are shown according to the technology used and the correlation with the energy consumption, including natural gas and electricity. The cases from other regions were taken from different papers already published: Blasco, I. et Al., 2000, Filippín, C., 1995, 2007, Czajkowski, J & Rosenfeld, E.,

[1] Data taken form INDEC, www.indec.gov.ar.

1990. The analysis shows how the consumers achieve what they believe are the well-being conditions through the over-consumption of gas for heating, exceeding any technological variable[2]. The city of Rio Grande is to the NE of the province of Tierra del Fuego at latitude 53º 40', longitude 67º 40' and 70 m above sea level and it has a population of approximately 60.000 inhabitans. According to the bioclimatic classification of Argentina (IRAM Norm 11.603, 1994), the city belongs to the VI area, very cold. The characteristics of this climate are of cold summers and harsh winters (Mid-annual data: Mid max. Temp.: 15.8ºC, Mid min, temp.: -3.6), with a RH 73%, very strong winds, during most part of the year from SW and 5482 degree-day (base 20ºC). The design temperature in winter is of -11.6ºC.

RESEARCH METHODOLOGY

Detailed winter and summer observations were carried out of the thermal-energy behavior under real conditons of use between 4th to 21st February, 2005 and 8th to 28th July, 2005. The following instruments were used: 22 HOBO microloggers (Trademark HOBO H8004), a weather station (Trademark HOBO H8 PRO) of two parameters and 5 digital thermo-hygrometers. The measurements of the hygrothermic behaviour of the housing were made within the period of five consecutive days including a whole weekend. This choice was made in order to gather information as complete as possible of the ways and patterns of use of the house and the energy, allowing as well the comparison between working days and days of rest. During the period measured, the information from the natural gas meter (NG) and electricity energy meter (EE) was taken into account to reflect the actual consumption. The data were then reflected in a thermic balance so as to be analyzed afterwards. (Diaz, C Y Czajkowski, J. 2006-2007).

Previous researches on the subject have focused on the energy variable and the habitability, in relation to the form and dimension of the buildings during summer on the one hand, and winter on the other. Taking into consideration the results of those analyses, alternatives for the improvement of the different operations were proposed, as well as a subsequent comparison of the level of energy saving achieved as opposed to the current situation. (Diaz, C. Y Czajkowski, J. 2004-2005-2006).

The present paper proposes a comparative analysis of the annual total consumption (TC) of energy in NG and EE (Eq. 2) per unit of habitable area (Eq. 3) of dwellings in different parts of the country. To carry out the analysis in the city of Rio Grande, the houses were chosen according to their similitudes in form and dimension.

$$CT = EEC + NGC \times 10.27 [KWh/year] \quad \text{(Eq.2)}$$

$$TC_{m2} = \frac{EEC + NGC \times 10.27}{m^2} [KWh/m^2.year]$$

(Eq. 3)

Table1 – Summary of the average dimensional, morphological and thermic indicators for each housing group

Technology used	Envelope Description (CS)	Characteristics of the constructive systems
Heavyweight construction system (8 cases observed) (≥ 400 Kg/m^2)	Wall: reinforced concrete slabs prefabricated with 1.5cm middle insulation Roof: slab mezzanine reinforced concrete	A(m^2) – 95 (average) V(m^3) – 247 Cf – 69.2 Ff – 0.38 Ef – 0.19 Km (W/m^2°C) W: 0.91 R: 2.00 G (W/m°C) - 2.26 NGC (m^3) – 6133.4 EEC (KWh/year) - 17320 
Tradicional construction system (6 cases observed) (≤ 250 Kg/m^2)	Wall: concrete blocks plastered in both faces Roof: metal sheet with insulation and tongue-and-groove at sight	A(m^2) – 80 (average) V(m^3) – 224 Cf – 69.4 Ff – 0.35 Ef – 0.62 Km (W/m^2°C) W: 2.15 R: 1.17 G (W/m°C) – 1.83 NGC (m^3) – 8231.9 EEC (KWh/year) - 16297 
Lightweight construction system (6 cases observed) (≤ 100 Kg/m^2)	Wall: System prefabricated with wood exteror insulation and interior plating.	A(m^2) – 98 (average) V(m^3) – 231.4 Cf – 65.4 Ff – 0.38 Ef – 1.00 Km W: 0.81 T: 0.86 G (W/m°C) - 1.47

[2] We call "technological variable" to the integration of different aspects in the construction of the public housing such as architectural design, adaptation to the place, construction system, behavior of use.

	Roof: Metal sheet with insulation and suspended ceiling	NGC (m³) – 7651 EEC (KWh/year) - 18022 

To obtain the diagnosis of the samples analysed, only the representative cases were selected grouping them in three categories according to the technology used in the construction. This selection was done based on the weight/m2 of each construction of walls and roofs. Another aspect that was taken into account was the energy consumption, both electricity and natural gas, to determine which the level of comfort achieved is, considering the architectural response to the environment and the behaviour of the social structures[3] of the housing. Complementary tables to the ones presented in previous investigations (Diaz C. and Czajkowski J., 2004-2005) were made, including: a. Dimensional aspects, b. Energy aspects. C. Technology, d. Comfort situation (Table 1)

The characteristics of the construction systems shown in Table 1 correspond to the average results of the housing analysed. The aim of this is to obtain an easy comprehension of the universe of study.

Where: A: the interior area that has to be heated in m2

V: the interior volume that has to be heated in m2

Cf: is the adimensional compactness factor (Czajkowski, 1990)

Ff: is the adimensional form factor (Czajkowski, 1990)

Ef: is the adimensional exposition factor (Czajkowski, 1990)

Km: is the measured coefficient of thermal transmittance (W/m2ºC) (Czajkowski, 2001)

NGC: is the natural gas consumption (m3)

EEC: is the electric energy consumption. (KWh/year)

A study of the energy consumed was carried out taking into account the general consumption of energy (KWh/m2 year) as a constant variable, i.e that the annual energy consumption per functional unit in NG and EE was unified. The consumptions were correlated to the global volumetric loss (G - W/m³. º C) the area (m2), and the habitable volume (m3). From this hyphotesis, previous cases that dealt with the same problem in different regions of Argentina were considered so as to be able to analyse and compare other behaviors in relation to the energy consumption in the housing (Blasco, 2000-2002; Czajkowski, 1990; Filippín, 1995). The criterion for the selection was based on the information supplied by already published papers with sufficient data to develop comparable graphics.

Table 2 – Previous data from different regions of the country

Blasco, et al. (San Juan)				
Code	**m²**	**m³**	**G (W/m²º C)**	**KWh/ m²/year**
1	60.6	183.3	N/R	75
2	73.57	228.08	N/R	66
3	70.58	198.32	N/R	67
4	86.58	236.99	N/R	59
5	52.48	146.95	N/R	96
6	62.4	174.72	N/R	83
7	54.96	181.38	N/R	83
8	56.42	147.32	N/R	68
9	69.26	171.03	N/R	63
Czajkowski, et al. (Buenos Aires)				
70	60	161	2.2	161.28
93	68	184	2.1	160.12
71	64	173	2. 9	176.16
91	61	162	2.4	194.11
137	56	160	2.8	195.69
68	74	203	2.5	183.87
94	60	167	2.9	168.37
241	60	167	2.7	139.41
288	39	106	2.9	143.60
Filippín, et al. (La Pampa)				
1	65.8	171.1	2.46	271.56
2	50.2	130.5	2.42	261.10
4	50.8	132	2.31	403.16
5	36.5	95	2.15	225.71
14	65.8	171.1	2.54	190.09
15	50.2	130.5	2.55	240.79
13	50.8	132	2.52	356.48
12	35.5	95	2.4	237.00

The data represented in Table 2 was selected according to dwellings with dimensional similitude; La Pampa and San Juan typologies correspond to social housing and, in the case of Buenos Aires, to private

[3] For the purpose of our análisis we will use the term "social structure" with the meaning of social class, which in turn is inseparable from the idea that there are gorups for whom their colective accion is, to a significant extent, base on the interets that are influenced by certain positions that the members of those groups have in society. (Atria, Raúl; 2004)

housing. The data collected were: square and cubic meters constructed, global losses (W/m2ºC), total energy consumption (K Wh/m2/year). According to the information from the previously published papers, in the case of Blasco, et. al. (San Juan) the data of the global losses G could not be obtained. In the Table it appears as "N/R"

The response to the total energy consumption with respect to the volume to be air-conditioned and to the global loss G (Fig. 2) was analyzed. If we observe these graphics, we can appreciate how the energy consumptions correlate directly with the construction system employed with respect to the climatic characteristics in which the dwellings are located, and their heating volume.

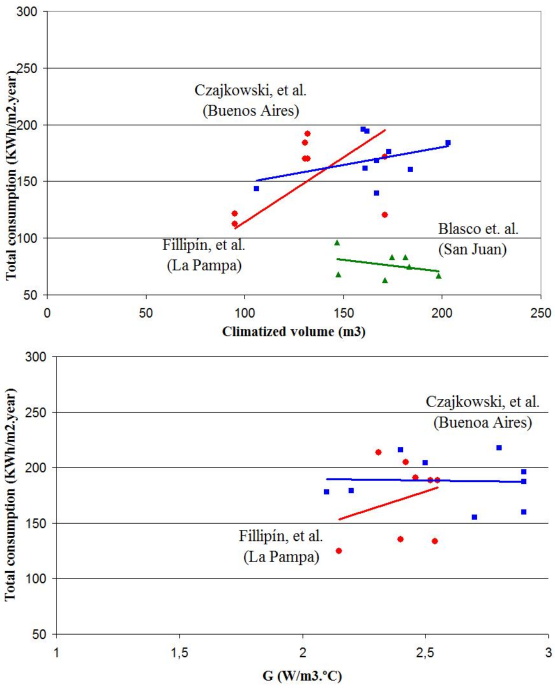

Figure 2 – Superposition of the total energy consumption with the volume and the G value respectively

As mentioned before, in Figure 2 the different cases were superposed with respect to their geographical position, giving as a result the energy consumption in relation to their dimensional characteristics. In the case of Figure 3, the graphics were made by unifying the variable of the energy consumption, in order to achieve this a 20º base day grade of each place was used according to the IRAM Norm 11604 (San Juan, 1275ºD/year and La Pampa, 1802ºD/year) so as to observe the behavior of the housing in relation to the energy consumption without considering the geographical variable. This unification will be useful to compare with our case study.

When these values are unified, we can observe how the consumptions, with similarities in volume and global losses, correlate and this shows that, despite the geographical location of the dwellings and their constructive characteristics, the users behave similarly in their way of fitting them out. In the following section the housing behavior in Tierra del Fuego will be analyzed together with the possibility of correlation.

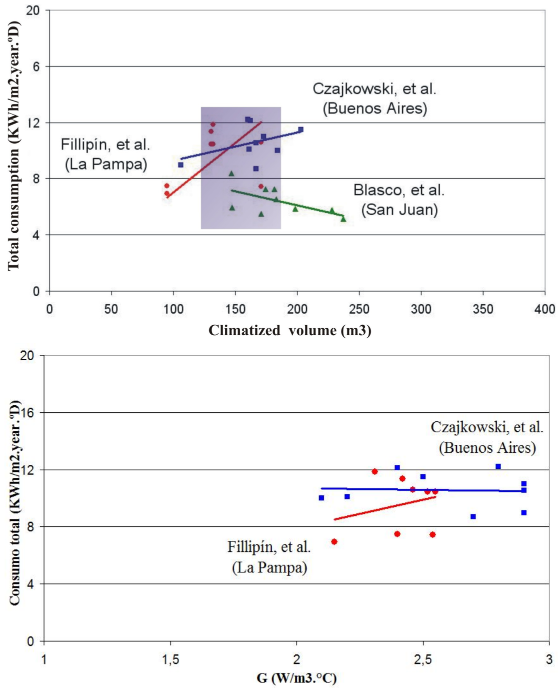

Figure 3 – Energy consumption in housing in different parts of the country unified in day grade with a 20ºC base.

RESULTS AND DISCUSSION

We begin from the hypothesis that the public housing estate in Tierra del Fuego presents apparent distortions in the energy consumption compared to other similar types in other areas of the country. Thus we propose, in the first place, an analysis of the typologies studied recalculating the total energy consumption with three variables, which should show lineal regressions with a positive tendency, i.e that the energy consumption "should" increase when the volume that has to be heated, the global volumetric heat loss coefficient and the exposition rate of the building envelope increase.

When we analyzed these variables for each case studied and their behavior under very cold climates, we observed as a common factor a very low correlation (a R2 that oscillates between 0,023 and 0,0041) between the daily loss of energy and the habitational area (see figure 4, 5 and 6). The blue dots represent the consumption according to what was observed.

Once the correlation for all the samples is made and when the annual thermal load is compared with the total energy consumption per housing, we can see that there is a great dispersion with respect to the real consumption. This difference between calculated (red dots) and measured (blue dots) shows that the users consume more energy than what was stipulated in the energy balances, which were made over the base of 20ºC (IRAM Norm 11604).

From the results of this analysis and according to the distortions that occurred, we observe that there are various interesting factors to discuss. First of all, we compare the measured consumption (analyzed) with the results obtained according to the energy balance, and we further analyze the cases studied and we group them according to the similitude in their interior mid-temperature, without making a distinction in the typology or technology used (Figure 4). For this latitude, the most used resource to maintain the habitational spaces comfortable is the NG, which means that the variable of the behavior of its used must be seriously taken into account.

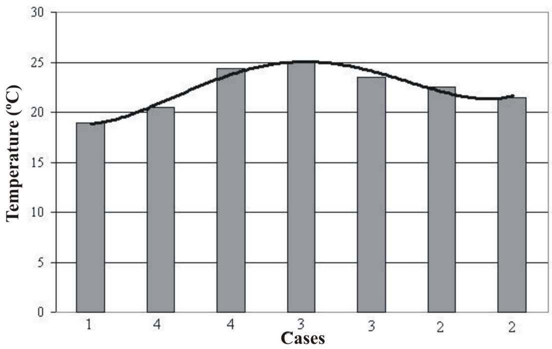

Figure 4 –Similitudes in the mid-temperature of the different cases.

According to the interior mid-temperature values and the relatively humidity we obtained a average value of 22.92ºC and 35.25%, for a summer exterior value of 11.31 ºC and 66.31 % and 1.87ºC and 86.7 % in winter respectively.

According to the measured data we can observe two factors that explain the high consumption of energy, the first one is the logical consequence brought by the search of comfort in the difference between interior and exterior temperature, but if we observe the measured exterior temperatures, it is necessary to "increase" 21ºC in winter and 12ºC in summer in order to reach this "comfort", which can only be achieved by a high consumption of energy.

However, the consumers seeking this level of comfort are not criticized here; instead, we argue that the same levels are reached by a very inefficient use of the energy, which is directly related to the mode of construction of the different housing and the global losses. (Diaz, C. y Czajkowsky, J.; 2004 – 2005-2006).

Another important factor that has to be taken into account is the NG subsidy that the national Government grants by law to the private business Camuzzi Gas del Sur S.A that supplies all the south of Argentina and most of the province of Buenos Aires. This subsidy is applied to the total value of the fuel (over the gas bill), which is higher as the latitudes increase until reaching a 65 % in the province of Tierra del Fuego, giving as a result a NG misuse that is poorly questioned by the consumers.

In order to understand this behavior the differences between the measured (observed) and the calculated temperature were analyzed so as to make the balances (20ºC), which gave as a result a difference of only three grades. Although this value may not seem significant, it is important to mention that in order to achieve this raise of temperature, a high consumption of energy is necessary because this difference does not occur lineally in the case of a building since there are various influencial factors such as infiltrations and air renovation.

After this analysis, we made the graphics once more with an interior temperature of 20ºC (calculated) and we superposed them with the calculated values (Figure 5, 6 and 7). We observed how the dispersion is corrected. In order to give an explanation to this, we show in the figures three big groups (heavyweight, traditional, lightweight), in which the behavior of the different construction systems in relation to the consumption can be observed. For a better understanding we marked in different colors each construction system. (Orange: Heavyweight; Green: traditional and Blue: Lightweight).

According to this last analysis, the dwellings constructed with the lightweight construction system have a high efficiency response to very cold climate, despite having a higher Ef because they are isolated houses. In the same way we verify the indicators of Km and G of Table 1.

If we observe the housing constructed with the traditional system (independent structures of reinforced concrete and concrete blocks), which also correspond to individual dwellings, we can appreciate a higher energy consumption as the area is smaller, this confirms what was proposed in previous investigations that showed a lower efficiency in the way or mode of adapting this construction system to a rigorous climate.

The opposed of these cases is the heavyweight construction system in which we can observe in the graphics a great difference between what was measured and what was observed. An explanation to this peculiarity is that, when making the energy balances from which the values for the calculation were determined (K and G values), it was done according to the documents and technique cards provided by *Sede Norte del Instituto Provincial de la Vivienda* of the city of Rio Grande, which, after the systematization and crossing of data with the measures done, it could be proven that in many of the observed cases there is a distortion between the characteristics of the construction in the documents and the measurements.

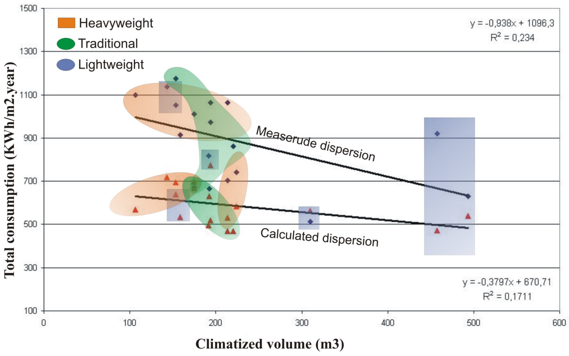

Figure 5 – Energy consumption according to the volume that has to be climatized.

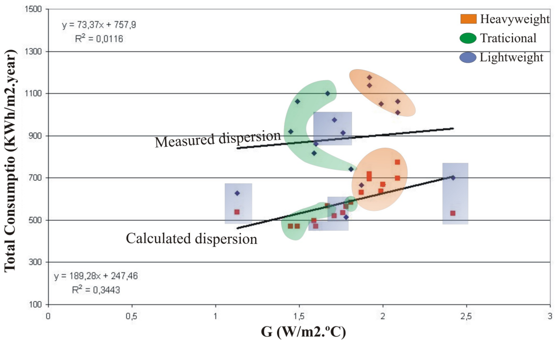

Figure 6 – Energy consumption according with the energy quality of the envelope.

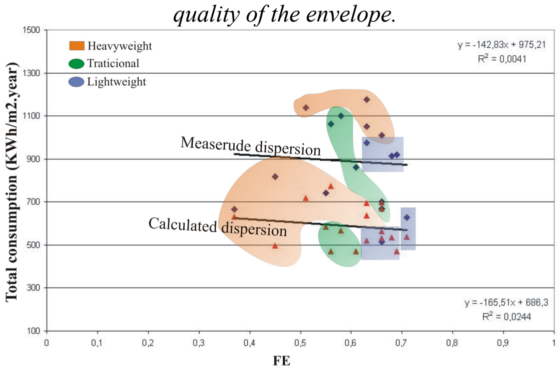

Figure 7 – Energy consumption according to the range of exposition.

We go back now to the previous hypothesis which proposes the unification of the grade days with a 20º base of the different typologies for different areas of the country; according to this and according to the IRAM Norm 11604, to the city of Rio Grande, where the study of these cases was carried out, corresponds a 5482º D/year (Figure 8).

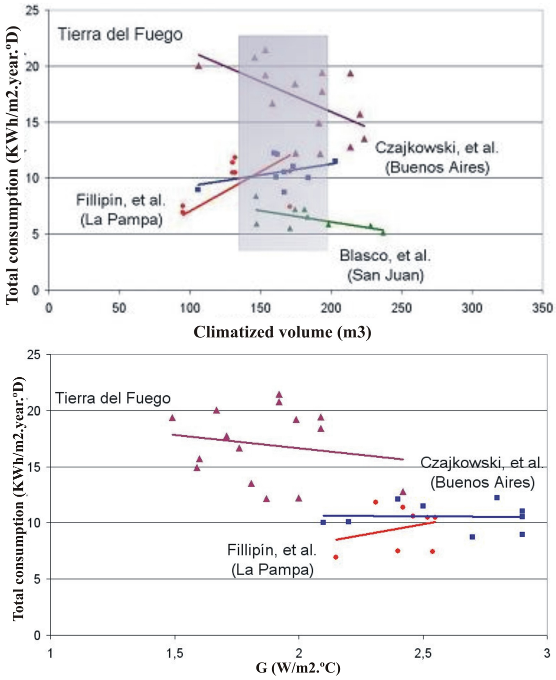

Figure 8 – Total energy consumption unifying the different housing analyzed in the country.

We can observe from these graphics that the behavior of the analyzed housing, with similar characteristics in the dimensional variable, moves away in the majority of the cases for other areas of the country. This situation confirms the proposed hypothesis as regards the deficiencies in the construction systems of the different operations already analyzed in previous papers, and the behavior of the consumers in order to achieve maximum "comfort" through the unmeasured use of energy.

CONCLUSIONS

It is clear from this analysis that in order to obtain more significant characteristics it is necessary to have a greater number of samples. We believe that with the scarce means available to carry out this scholarship, the results are only promissory with respect to the social housing, either as regards typological diversity, construction and technology or as regards habits and ways of using the energy in very cold climates.

It can be inferred that the high levels of energy consumption are related to the behavior of the consumers, which are a consequence of the large subsidies granted by the province. This entails that in other regions of the country, with similar habitable volume and same day grade, the energy consumption is notably lower. Not only for achieving a more modest comfort that in Tierra del Fuego, but also as a direct result of the energy cost.

The comparative analysis shows that while in the rest of the country there is a correlation between the energy consumption and the housing volume, in Rio Grande this does not occur (R2=0.0116). This marked dispersion is caused by the subsidies which make the consumers lose the capacity to value energy. This implies a random behavior between family groups that consume the necessary to maintain their housing around 20ºC while in others levels over 24ºC were registered.

The possible application of the data of the analyzed housing form the other areas of the country would allow the creation of an indicator as a base for the comparison between the behavior and the use of energy, exceeding the technological variable and the mode of energy use.

As regards the housing in Tierra del Fuego we can recognize a possible real implementation in their redesigning. After this analysis, it has to be considered the use of instruments for investigation and development that respond to the technological, economic, social and institutional context of the region considered. As a complement to this, it is necessary to propose the formulation of policies for economy incentive that favor the adoption of exigency levels superior to the already established in the *Condiciones mínimas de Habitabilidad Higrotérmica* of the SEDUV (C level of the IRAM norm 11604). It is also highlighted the need of a provincial law to provide a group of measures between the different levels of the government.

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