ENVIRONMENTAL INDEX OF ENERGY CONSUMPTION IN BUILDINGS APPLIED TO PARAMETRIC MODEL DESIGN

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ABSTRACT

This work is part of a doctoral thesis about optimization of parametric bioclimatic design. We develop two bioclimatic indexes of heating and cooling for typical winter and summer days respectively, which are optimised by means of genetic algorithms (GA) [1].
The object is a high-rise building with multiple uses, located in a plot of urban land, which adequates to Buenos Aires City Environmental Code [2]. The efficient envelope fulfils the Law of Thermal Conditioning in Buildings for Buenos Aires City and IRAM Standards 11604 [3] and 11659/1-2 [4].
After parameterizing the building geometry, we introduce solar thermal loads, transmission loads and internal loads. We employ our own climatic data from the Laboratory: hourly solar radiation and temperature.
Then, we run the program successive times in order to obtain a set of solutions, which have equivalent energy performance but different spatial configuration. We utilize a genetic algorithm (GA) to optimise the process [5].
Based on the results, we can analyse which variables influence the energy performance of the alternatives.
This tool proves to be effective to design and optimise architectural solutions for a high-rise building, while giving the designer more options than traditional design method. We verify the hypothesis of the incidence of envelope geometry on energy consumptionby means of these new indexes.
The calculations of these new indexes—B_{heat} and B_{cool} —let us evaluate simultaneously both parameters, providing a common basis of comparison: 24-hour energy consumption of typical winter and summer days.
We can affirm that energy efficient design cannot let apart summer condition for our bioclimatic zone (humid temperate) IIIb (IRAM 11603) [6]. Nevertheless, the above mentioned law in Buenos Aires Province only require a minimum G_{heat}, taking into account just winter condition. The same happens with IRAM Standard 11900 about energy efficiency labelling.

Keywords: bioclimatic indexes- energy consumption

1.-The issue

The architectural design has become a step isolated from the production process, because of the high complexity of the problems that involves this process and the specialization in the architectural production.

This tool helps the designer in the first steps of the project, when he takes decisions that will influence along the development, construction and lifespan of the building as well as on maintenance and operation costs.

In this case, we design a high-rise building with different uses. We select this typology because it is a common one in the professional work. We pretend to generate a reflection on our design research field.

2.-The building and its environment.

The building comprehends offices, housing and mixed use of both activities, divided in three volumes with different sizes. The areas, quantity of storeys and heights are shown below (Table 1)

Uses	nº floors	Area /floor	Floor height	Volume height
	u	m^2	m	m
housing	10	300	2,75	27,5
offices	20	250	2,75	55
mixed	15	250	2,75	41,25
Total area		11750		

Table 1: Uses and areas

The urban plot is a 50m x 50m square, limited by streets on three sides. It looks onto the river in the East side. The bioclimatic zone is humid temperate. It is situated in the metropolitan area of Buenos Aires (IRAM 11603) (Fig. 1)

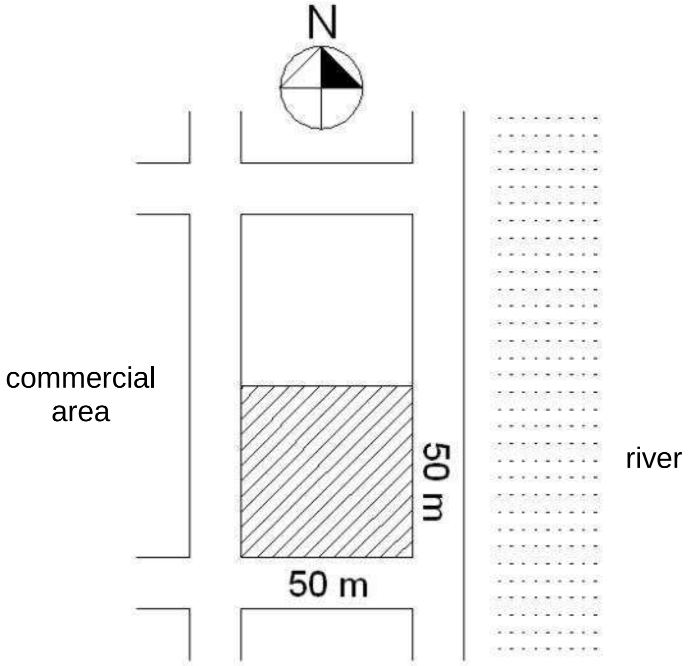

Fig. 1 “Plot relative location” Source: the authors

3.-Data entry

External data —which determine the building shape and materiality— can be classified into two categories.

“Non- parametric” data do not admit variations, they are factual data:

- Plot dimensions, orientation and bioclimatic zone (climate)
- Building requirements: area and volume, according to the functional uses.
- Building code restrictions: building lines, maximum building area, volume and heights, urban indicators (land occupancy factor, total occupancy factor, etc.)

“Parametric” data are defined as ranges, they can vary and GA can affect them:

- Building geometry: location in the plot, envelope shape, fenestration percentage, arrangement of the different modules. It varies according to a range defined by the designer. GA optimises it
- Envelope efficiency level (walls, windows and roofs). IRAM Standard 11605 [7] determines three levels: A, B y C, the designer determines the level. GA does not affect it because it would result the most efficient level but technical or economically unfeasible. We choose a level between A and B, considering that Law 13059/03- Energy Efficiency in Buildings [8] in the Buenos Aires Province requires at least, level B.
- Envelope thermal transmittance for the calculation of the G Volumetric Coefficient of Heat Losses (G_{heat}) (IRAM 11604) and G Volumetric Coefficient in Cooling (G_{cool}) (IRAM 11659-2).

4. Building Parameterization

We link data by math-logical operators. We use Rhinoceros, a 3D modelling program by NURBS [9] and a parameter design plug-in, Grasshopper [10]. We employ Galapagos, a GA for optimizing energy consumption [11]. We can observe the layout of one solution in fig. 2.

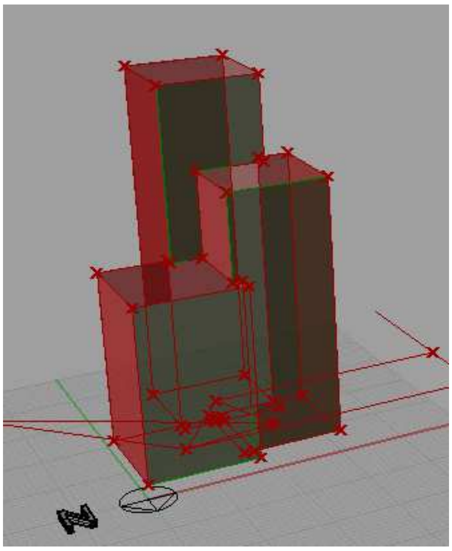

Fig. 2 “Building Volume”. Source: the authors

We group together the façades by orientation and assign a percentage range to windows, according to IRAM Standard 11603.

We adopt the following percentages:

- North Façade: 50%
- South Façade: 10%
- East Façade: 40%
- West Façade: 30%

5. Bioclimatic variables

We need to define the envelope transmittance to calculate thermal losses and gains. We consider walls, windows and roofs.

5.1. Envelope Transmittance in winter

The range for winter in our bioclimatic zone is 0.38 W/m^{2}K<=K$_{muro}$ <=1.85 W/m^{2}K, which corresponds to the three levels— A, B and C— determined by IRAM Standard 11605 [12]. GA does not affect this variable because, as the same as happens with fenestration, it would tend to be the minimum allowed. In our experiment, we adopt K= 0.45 W/m^{2}K, between A and B levels. Table 2 shows the wall layers Thermal transmittance for winter is the same as for summer, being maximum design temperature (MaxDT), 31.2°C for summer.

IRAM Standard 11601	K		
PROYECT	High-rise building		
ELEMENT	wall		
SEASON	winter	Horizontal heat flux	
BIOCLIMATIC ZONE	IIIb		
Comfort level according to IRAM 11605		MinDT: 1,7 °C	
	width	λ	R
Layer	m	W/mK	m^{2}K/W
Exterior surface resistance			0,04
Outer plaster	0,03	1,16	0,03
Expanded polyestirene δ: 30 kg/m^3	0,05	0,032	1,56
Vapour barrier			
Hollow ceramic brick	0,18		0,41
Gypsum board	0,0125	0,45	0,03
Interior surface resistance			0,13
TOTAL			2,2
Element thermal transmittance W/m^{2}K			0,45
Thermal transmittance level B (IRAM 11605) W/m^{2}K			1

Table 2: Wall thermal trasmittance- winter

Iram Standard 11507-4 [13] prescribes a thermal transmittance range between 2 y 4 W/m^{2}K for windows. Following the same criteria as for walls, we adopt K= 2.61 W/m^{2}K, which corresponds to PVC double glazing with 12mm single air chamber and 6mm transparent glasses (IRAM 11507-4).

The range for roofs comprehends from 0.32 to 1 W/m^{2}K. We adopt K= 0.33 W/m^{2}K, following the same criteria as we explained above. Level B, required by the mentioned law is 0.83 W/m^{2}K. The different layers of the roof are detailed in Table 3.

In the case of the perimeter, we adopt a thermal transmittance of K=1.03 W/m^{2}K, corresponding to floor perimeter insulation (level B).

Comfort temperature for winter is 20°C (IRAM 11603).

5.2. Envelope thermal transmittance for summer

Wall and roof composition satisfies summer conditions for IRAM Standard 11605. The required level (B) is 1.25 W/m^{2}K for walls and 0.48 W/m^{2}K. for windows. Fenestration always fulfills IRAM Standard 11507-4.

IRAM Standard 11601	K		
PROYECT	High-rise building		
ELEMENT	roof		
SEASON	winter	Ascending heat flux	
BIOCLIMATIC ZONE	IIIb		
Comfort level according to IRAM 11605		MnDT: 1.7°C	
Layer	width	λ	R
	m	W/mK	m^{2}K/W
Exterior surface resistance	0,005		0,04
Asphalt membrane	0,05	58	0,00
Polyurethane foam open cells	0,05	0,022	2,27
Concrete layer	0,1	1,13	0,04
Concrete subfloor	0,05	0,76	0,13
Reinforced concrete compression layer	0,12	0,97	0,05
Concrete slab with EPS	0,05	0,44	0,27
Suspended cieling		0,49	0,10
Interior surface resistance			0,10
TOTAL			3,01
Thermal transmittance of the element W/m^{2}K			0,33
Thermal transmittance level B (IRAM 11605) W/m^{2}K			0,83

Tabla 3: Roof Thermal transmittance in winter

5.3. Air changes (n)

The quantity of air changes per hour is 2, according to Law 13059/03 DR 1030/10, As this value is too high for an efficient building, we adopt the analytical method (IRAM 11604) [14] which is specific for this case.

As the building height increases, the openable area of the windows must be reduced because wind speed grows exponentially. We consider suburban soil roughness to be 0.4 and average wind speed, 3.9 m/s at 10m high (IRAM 11603). Then we calculate the wind speed every 10m high [15]. With these values, we calculate the decrease of window joints length, as inversely proportional to wind speed increment.

In order to calculate the quantity of air changes, we utilize a weighted average, according to the air volume of each floor (eq. 1). The GA considers a unique air volume, without separation for each floor. We divide the building every 10m to determine the openable window joint lengths (Fig. 3)

$$n = \frac{\sum \mathrm{n_n} \times \mathrm{V_n}}{\mathrm{V}} \tag{1}$$

n_n= number of air changes for each sector, according height

V_n= sectors in which the building is divided every 10m high

The obtained range is between 0.52 and 0.68 air changes/h for the different solutions.

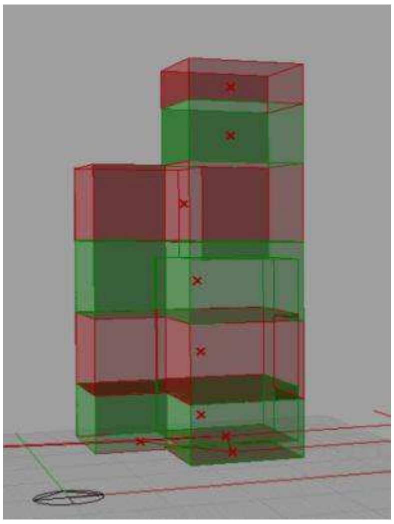

Fig. 3: “Division of the building according to air changes per hour” Source: the authors

6. Bioclimatic heating index

When calculating the volumetric heating coefficient (G_{heat}) (IRAM 11604), we consider an envelope without solar gains, only losses. There are calculation methods like the Solar Load Ratio [16] and the program Optimix [17], which add solar gains to the thermal balance of the building. In order to calculate solar gains for a typical winter day, we apply a similar method to the one employed in IRAM Standard 11659-2. This method considers thermal gains only at solar peak hour (Q_{cool}). Instead, we consider thermal gains and losses for each hour, during a whole typical winter day, (eq. 2)

$$B_{heat} = \sum_{i=1}^{n=24} Q_c + Q_a - Q_s - Q_o \qquad (2)$$

Q_c : envelope thermal losses by conduction (W). We consider each element (walls, windows, roofs) transmittances, their areas together with losses by floors in contact with soil. We calculate the product between this sum and the difference between the outdoor and the indoor comfort temperatures.We apply this calculation to each hour of a typical winter day, that in our case is July, $1^{st.}$ (eq. 3):

$$(\sum K_w \times A_w + \sum K_w \times A_w + Per \times L_f) \text{ x } \Delta t \qquad (3)$$

To calculate Δt, we consider average maximum and minimum temperatures and we obtain hourly temperatures.

Qa :the product among thermal losses by infiltration, building volume and Δt (eq. 4):

$$Q_a = \left(0.35 \times \frac{\sum n_n \times V_n}{V}\right) \text{x} V \text{x} \Delta t \qquad (4)$$

Q_s : solar gains by glazing. To calculate the solar thermal load (W) we proceed as shown in eq. 5)

$$Q_s = \sum A_w \text{ x } K_w \text{ x } I_s \text{ x } F_s \qquad (5)$$

A_w: window area m^2

K_w:thermal transmittance (W/m^2K)

I_s: solar radiation on building façades and roofs. IRAM Standard 11659-1 [12] provides solar radiation on planes according to orientation and hour if the day.

F_S: solar exposure 0.40 for DVH 6+12+6 glazing.
Q_o: internal gains: people, equipment, lighting (eq.6). Occupancy depends on the different uses of the building. We consider 100% from 7PM to 8AM and 50% from 8AM to 7PM for housing. Offices have an occupancy of 100% from 9AM to 6PM and 0% from 6PM to 9AM. Mixed use building has 50% occupancy during the whole day.

$$Q_0= Q_{peop}+Q_{light}+Q_{equip} \tag{6}$$

Q_0= thermal load by internal gains
Q_{peop}= thermal load by people and metabolic heat coefficient (eq. 7):

$$Q_{pop}=N_{peop} \, . \, M \tag{7}$$

Q_{light}= thermal load by lighting (eq. 8):

$$Q_{light} = \sum_{i=1}^{n} q_{light}.A_i.C_{T_i} \tag{8}$$

q_{light}= lighting internal gains
A= building area with lighting
$_{Ti}$= thermal coefficient depending on the type of lighting
Q_{equip}= equipment thermal loads (ec. 9):

$$Q_{equip} = \sum_{i=1}^{n} q_{ligh_i}.N_{light_i} \tag{9}$$

Q_{light}= light thermal gains
N_{light}= number of lights

7. Bioclimatic cooling index (B_{cool})

To calculate this index, we obtain hourly thermal gains for a typical summer day, using the same method employed with G_{cool} (IRAM 11659 1-2) [3]. We consider not only the envelope but the hourly solar radiation as well. We calculate hourly temperatures, using the same method as with G_{heat}.
Humidity remanis constant during the day in order to simplify this tool, designed for the first steps in the design process.
Occupancy is the same as for B_{heat}.
In order to consider solar radiation incidence on the envelope— according to orientation and materiality— we replace the máximum design temperature for the sol-air temperature.
In this kind of analysis, thermal gains and losses vary hourly, considering if outdoor temperature is higher or lower than indoor comfort temperature. The algebraic sum of these values results in the total thermal load for a typical summer day.

8. Integration of variables to optimize. The use of GA

The variable inputs are the location of the volumes. The envelope materials do not feed the GA, even when they are parameterised. The GA iterates until it finds the alternatives that show the lowest values for B_{cool}, calculating at the same time, B_{heat}.
B_{heat} results are separated into three categories: the first does not considers neither solar gains nor internal gains (people, lighting and equipment) only losses, the second one, subtracts solar gains to losses and the third one, subtracts solar gains and adds internal gains to losses. Besides, we calculate losses per m^2 for both typical day.

9. Results analysis

After running the program as many times as we determine, we choose the best six solutions that the GA finds. Table 4 shows these results. Figures 4 (“Volumetric alternatives 1 & 2”), 5 (“Volumetric alternatives 3 & 4”) and 6 (“Volumetric alternatives 5 & 6”) show the six different building arrangements. We can observe a great variety of energy efficient solutions that fulfill the required requisites.

alt.	B_{heat} envelope losses	B_{heat} envelope losses-solar gains	B_{heat} envelope losses-solar gains+internal gains	Energy consumption /area	B_{cool}	Energy consumption /area
	kW/día	kW/día	kW/día	Wm2/día	kW/día	Wm2/día
1	3919,85	894,95	-1111,40	-100,64	6222,5	563,46
2	3961,89	813,33	1036,00	92,63	4195,8	375,16
3	4765,88	1673,34	1303,10	120,83	7655,9	709,88
4	4319,63	1348,56	1333,50	117,94	13075	1156,40
5	4287,64	992,81	1462,20	130,29	9830,1	875,94
6	3994,50	927,88	-1187,00	-112,58	7096,7	673,07

Table 4 Alternatives, B_{heat}, B_{cool} and energy consumptions per m^2

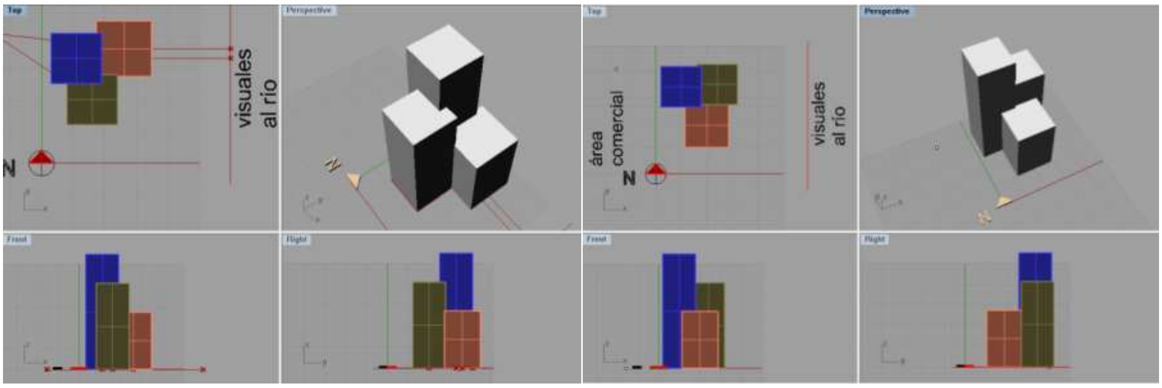

Fig. 4” Volumetric alternatives & 2”. Source: the authors

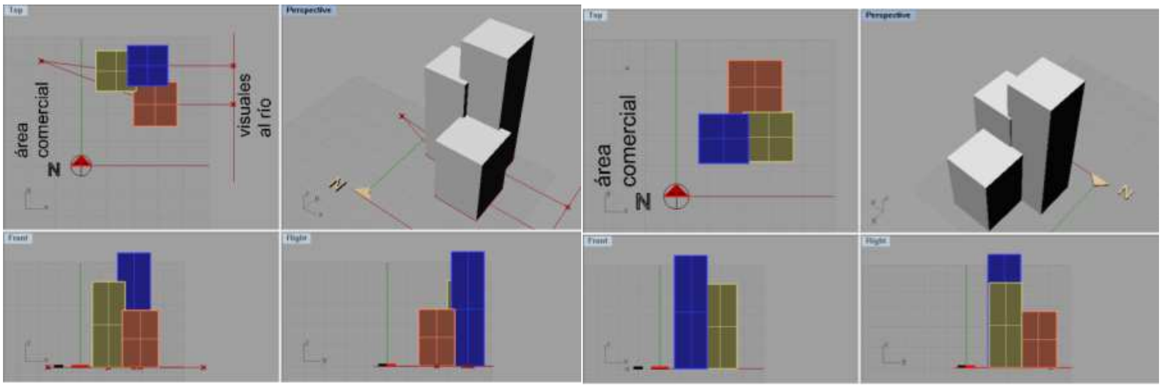

Fig. 5 “Volumetric alternatives 3 & 4”. Source: the authors

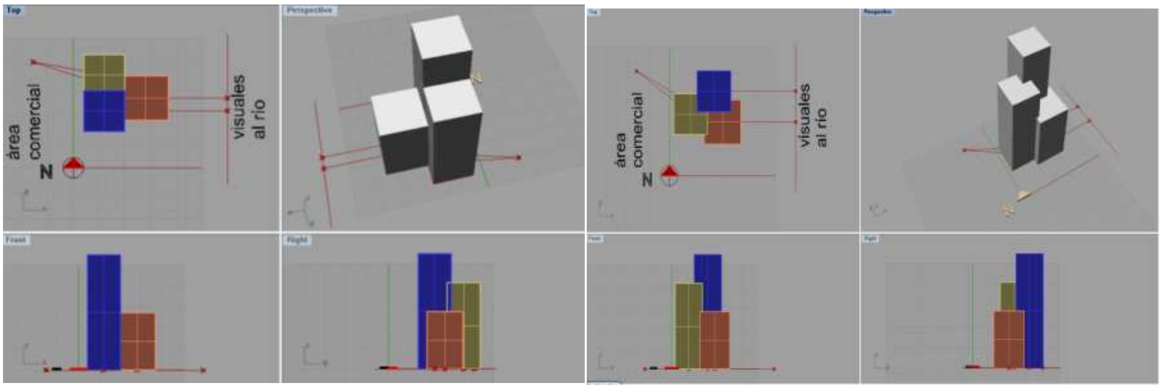

Fig 6 “Volumetric Alternatives 5 & 6”. Source: the authors

On the basis of the results, we can analyse which are the variables that affect the energy performance.

In relation to these indexes B_{heat} y B_{cool}, we can see the impact of summer condition in building design for temperate zone IIIb (IRAM 11603). Energy consumption for cooling determines to primarily adopt efficiency measures for summer and not for winter, as Fig. 7 (“Comparison of B_{heat} considering solar and internal gains and B_{ref} for the different alternatives”) shows.

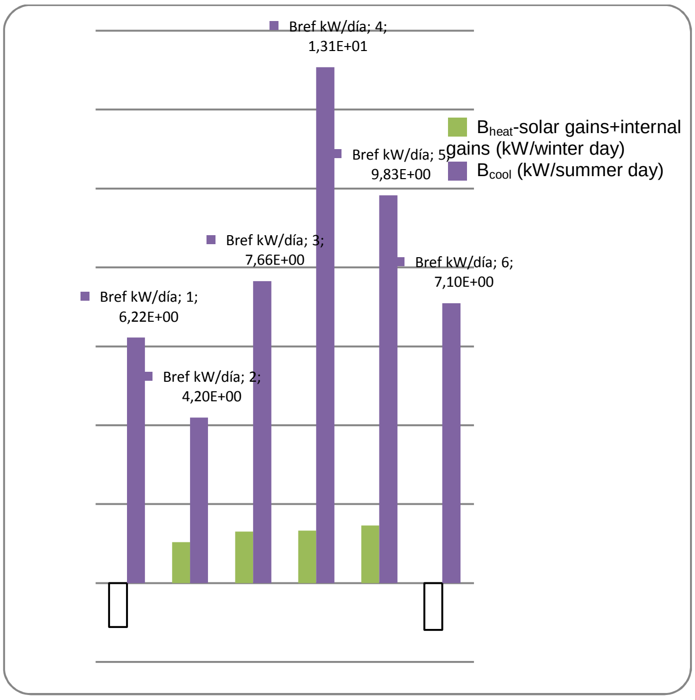

Fig. 7 “Comparison of B_{heat} considering solar and internal gains and B_{ref} for the different alternatives”. Source: the authors

10. Conclusions

This digital tool proves to be effective to design and optimise energy efficient high-rise buildings, offering to the designer more options than if he use a traditional design method. In one operation, we solve the building geometry and its energy performance, in real time and in a feedback process. We verify the dependence of the envelope geometry in energy consumption while fixing area, materiality and occupancy, founding six possible solutions.

The calculation of new indexes for heating B_{heat} and cooling B_{cool} lets evaluate simultaneously both parameters, providing a common basis of comparison: hourly energy consumption for both winter and summer typical days. If we only evaluate

G_{heat} (IRAM 11604) and G_{cool} (IRAM 11659), it is not possible to compare them. Based on the results of these new indexes, we can assert that energy efficient design cannot disregard summer condition for this humid temperate bioclimatic zone (IRAM 11603). However, the current energy efficiency law in Buenos Aires province requires a minimum G_{heat}, only considering winter condition. The same issue applies to IRAM 11900 Building Energy Labelling. Probably, we should tend to a normative model that— without using an expensive method of dynamic simulation like Greenbuilding LEED protocol—could offer reasonable, inexpensive and quick results with a steady state model. In some extent, it is the proposal of this work.

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