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# Energy storage for residential dwellings. Methodology to improve energy efficiency and habitability

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A B S T R A C T

The paper aims to develop a methodology for energy optimization of the residential sector which proposes a proper use of energy storage technologies applied to massive retrofitting. This research began as a mitigation measure against the low thermal qualities of existing buildings in Argentina, the energy crisis and its environmental consequences. Strategies of morphological and technological-constructive criteria according to representative typologies were adopted. In order to evaluate energy consumption, a method was implemented which considered the relationship between energy savings and initial investment cost through an "energy-economic efficiency index". An application example on an existing building is exposed in order to visualize the analysis developed. Its implementation on relevant typologies allows us to expand the results and to analyse mitigation levels in the representative urban areas and thus replicate improvement proposals promoting a significant reduction in residential consumption considering its envelope as energy storage. The results show that savings of 20% would be achieved in the sector, noting that the participation of this sector represent almost a quarter of the national energy matrix. This (theoretically) reduction in energy demand is beneficial both for all individual users (who can amortize initial retrofitting costs in a brief time of 10 years or less according to energy subsidy levels), as for the group of the population and the state, because this reduction would allow dispensing with fuel imports and reframing subsidy policies. In conclusion, this paper shows how the proper use of energy storage technologies in residential dwellings may largely reduce the energy needs while delivering better indoor environment quality and providing the basis for future implementation of renewable sources.



## 1. Introduction

The energy crises occurred worldwide from the '70 s led us to think about the future of habitat and natural resources. To reverse this situation, challenges to the different sectors involved were included such as: political governance, economic activity, social structure and individual consciences.

In this way different countries took actions to define thermal quality standards by the regulations of new construction features; and in some cases, retrofitting existing buildings on massive scale.

In the case of the building sector and particularly the residential one, the contributions provided by developed countries are considered, which have successfully introduced measures related to the rational use, conservation, efficiency and finally with the implementation associated to the basic and fundamental principles of the "Passive House".[1] In the first instance they have analyzed and developed massive rehabilitation measures in the existing building and during the recycling process, the normative basis have been set for the new building. In Europe and the United States conservation techniques and Rational Use of Energy (URE) achieved significant results after three decades of its release.

[1] "A passive house1 is an energy-efficient building with all year-round comfort and good indoor environmental conditions without the use of significant active space heating or cooling systems. The space heat requirement is reduced by means of passive measures to the point at which there is no longer any need for a conventional space heating system; the air supply system essentially suffices to distribute the remaining space heat requirement. A passive house provides a very high level of thermal comfort and whole-house even temperature. The concept is based on minimizing heat losses and maximizing heat gains, thus enabling the use of simple building services." http://www.seai.ie/Publications/Your_Building_Publications_/Passive_House/Passive_House_Retrofit_Guidelines.pdf.

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Energy reductions achieved in the first decade of intervention ranged between 15 and 45% in the residential sector. For example, the energy consumption of the countries of the Organization for Economic Co-operation and Development (OECD) grew only 4% between 1973 and 1985, while the Gross Domestic Product (GDP) grew, in the same period 30%" [1]. In Spain, from 1490 decree June 1975, the first steps were taken to reduce energy consumption and the development and state support of R & D programs for alternative energy sources that do not require the use of oil demand [2]. The Institute for Diversification and Saving of Energy (IDAE) as State Society of the Ministry of Industry and Energy of Spain, was commissioned to carry out interventions in the residential sector and services from the municipalities, obtaining very significant achievements that were published in different media [3].

We can also cite the example of France where the actions promoted by the Environment Agency and Energy Management (ADEME), the French Agency for Energy Management (AFME) and the Scientific and Technical Committee heat Industry (COSTIC) among others, carried out the organization and implementation of systematic recycling of much of the existing buildings. In this case the intervention of climatic zones is highlighted, detailing the construction aspects and consumption disaggregated by source, for individual and collective housing. Demands were analyzed by source and type of use, the equipment, the upgrading complexity, the number of users as well as the implementation and dissemination of relevant regulations. Numerous publications aimed at training and scientific and academic developmen[2] were performed. As the above examples, the other developed countries acted accordingly, beyond the peculiarities of each process.

In this way, most of the European countries successfully introduced measures and principles of Passive House Retrofit (PHR) in the rehabilitation of existing buildings [4]. Currently the energy savings achieved may vary within a range of 80–95% depending on the types. For example heating demand has been reduced in some cases 150–280 kWh/$m^2$ year to less than 30 kWh/$m^2$ year. The results show that the standard of 15 kWh/$m^2$ year of Passive House (PH) can be achieved. It has also been checked in different countries, that rehabilitation of buildings according to standards PHR is economically viable in the current energy context [5], and continue with the development of research evaluating its viability [6,7].

In our region, the effects of the oil crises generated similar actions with political-institutional scenarios, but with prospects in levels demands somewhat lower and prospects in terms of resources, more encouraging. For example, Brazil has begun to develop different policies to support and/or encourage self-sufficiency. Actions to study the demand and to rationalize the consumption, with emphasis in terms of academic and scientific, technological and instrumental capabilities are coordinated. Although there were very unstable political-institutional instances in the final decades of the twentieth century, the work done laid the foundations for today's existing programs and for the formation of trained academic staff.

We can cite as an example the National Association of Built Environment Technology that promoted the development and research of technological aspects and comfort applicable to the building industry throughout the national level. A recent example is the HABITARE/FINEP/2004 Project. It works on standardization in the Environmental Comfort and develops themes related to thermal, lighting and acoustic performance in buildings. These works are carried out in the Executive Unit of the Federal University of Santa Catarina (UFSC); Department of Civil Engineering, based on the main Researches in Construction. Another example is carried out by the Ministry of HABITAÇAO State Government of Sao Paulo, which includes a “Sustainability and Innovation Program in the popular habitat” It consists in the analysis and development of dwelling proposals of individual and collective housing typology of medium density clustering, efficient use of energy and passive standards.[3]

However, Argentina did not perform any of these actions, and instead, has continued increasing energy demand. In this context related to the residential sector, both real estate markets as state initiative in social housing have employed materials and construction technologies of low thermal quality in order to obtain a reduction of the initial cost. The consequences of this fact are registered in high operating costs that each house has to face, and the deficiencies of indoor comfort. These costs are daily paid by users and by the state itself through actions of energy subsidies.[4]

Nowadays, four decades after the “oil crisis”, the National Government has encouraged as part of the interest and priority on rational and efficient energy use, the Decree 140/2007. And the Law N° 13,059 for the province of Buenos Aires, which main purpose is to set and enforce minimum thermal conditioning in order to contribute to improve inhabitants life quality; from minimizing energy demand and reducing environmental impact through efficient energy use.[5]

Furthermore, it is important to note that existing housing stock in Argentina produces a significant impact on the national energy matrix, representing a consumption of 23% [8]. From this demand, 50% is destined to heating [9,10]. That is the reason why it is considered essential to act on this sector, considering the buildings envelopes as an energy storage such as to minimize energy demand by incorporating more efficient technologies through massive retrofitting techniques.[6,7] This allows a substantial improvement of habitability conditions (being able to reach the minimum required by law 13059) and future restructuration of energy equation reducing demand.

According to this problem, we work on a methodology that fully addresses the technological-constructive proposals for energy improving in different residential buildings units; considering their representation in different urban mosaics [11] and the city as a whole. Once the building typologies are identified, we analyse the

[2] Among them we can mention the diagnostic manuals " Guide de diagnostic thermique" published by the AFME in 1987, software such as Media-Mi and the Media-Lc oriented to the integral energy assessment of commercial and dwelling buildings developed by AFME, 1988; and booklets for diffusion by regions and areas of intervention under the slogan “Pour en savoir plus”, developed by the ADEME, 1988.

[3] Ministry of HABITAÇAO State Government of Sao Paulo, which includes a Sustainability and INOVAÇÃO Program of “Sustentabilidad e Inovaçao na Habitaço Popular. O desafio de propor modelos eficientes de moradia. 2010.”

[4] The National Government subsidizes the cost of natural gas and electricity reducing it to values below 40%.

[5] To this effect, the technical standards of the Argentine Institute of Standardization and Certification (IRAM) of thermal conditioning for buildings and windows are being implemented.

[6] In our Institute, an experimental measurement kit of heat flow (Heat Flow Meter) at steady state was developed. It works by placing the element tested between a hot source and a cold source and measuring the heat flow that overpasses it and the resulting surface temperatures. From these data the thermal transmittance coefficient and the thermal materials conductivity and constructive parameters are calculated. Currently seven alternatives walls, roofs and representative openings are being tested from the residential sector of La Plata, and two possible alternative recycling (technical and economic) for each one, in order to assess their thermal response under real conditions and contrast them with the theoretical results.

[7] G. San Juan, C.Discoli, G. Viegas, C. Ferreyro, L. Rodriguez. “Proyecto de viviendas bioclimáticas de interés social. Tapalaqué, Provincia de Buenos Aires”, *Energías Renovables y Ambiente.ERMA*, Vol.341, ISSN 0328-932X. Revista de la Asociación Argentina de Energías Renovables y Ambiente, ASDES. 2015.

technology, viable for our technological-socio-economic context, to be implemented on each element of the existing envelope. Detailed study of the different building typologies and their envelopes allows us to expand the results to urban mosaic, and finally assess its impact citywide. The evaluation methodology developed is displayed and Fig. 1 shows the scales of analysis referred to the city of La Plata, Argentina (Fig. 2).

## 2. Classification of existing residencial buildings and evaluation of technological-constructive envelope proposals as energy storage

A significant part of the urban area is composed of residential building typologies. These typologies can be differentiated by historical periods and can be characterized by their building systems. The study of each one allows to analyse their constructive characteristics, their pathologies, and determine the thermal-energy quality of their envelopes as energy storage. Knowledge and systematization of these aspects enable us to move forward on conceptual and instrumental proposals of envelopes improvements oriented to massive application and energy storage. We are referring to the evaluation of constructive aspects, thermal efficiency analysis for representative cases, energy consumption calculation and habitability improvement, as well as thermal comfort conditions. All these aspects must necessarily be compared with the investment cost.

To this purpose, we present an approach to the study and classification of existing housing in characteristic urban mosaics of La Plata, from its morphological, technological and constructive categorization. Representative cases are selected for thermal and economical evaluation in order to apply the technological-constructive proposals of massive retrofitting [12] and energy storage. With the results obtained we built charts that systematize the main variables of each typology, their thermal characteristics and the relation to economic costs. We also compared energy-economic efficiency of each proposal by using the "efficiency index", which guides us in selecting best options for intervention in energy storage.

### *2.1. Study and classification of the residential sector*

The residential sector of La Plata city has been selected. Strategies based on high representativeness, using two basic levels as selection tools were applied: i) *morphological classification* and ii) *technological-constructive classification*. We also proposed a third level of analysis, consisting of the relationship of both classifications by disaggregating them in iii) *envelope elements and their joints* or encounters, according to systematic implementation of retrofitting proposals.

#### *2.1.1. Morphological classification*

For the identification and delimitation at morphological level, typological criteria of representativeness was adopted [4,13,14], whose main advantage consists in its synthesis ability and context recognition. This approach allows us to include the 260,000 dwellings of La Plata into a small number of representative samples, easily recognized by professionals in the field and by non-specialists.

To this propose we adopted the classification developed in the AUDIBAIRES project [6]. This project is based on the analysis of URE potential (Rational Use of the Energy) and its policies in the Metropolitan Area of Buenos Aires in the 80s. Typological representative dwelling have been audited, 392 were audited globally and 135 in detail. The values of "G" ("*global thermal losses coefficient*" (G) according to IRAM 11604), for the types studied were acceptable for the IRAM 11604/86 but were far from meeting European standards. From this study we detected seven morphological typologies, representative for La Plata: *"casa chorizo" house*; *Californian chalet*; *Rationalist house*; "*casa cajón*" *house* (private or state); *Rental house* (corridor, four doors, in height); *monoblock*; *horizontal property* (HP) building in height (between medians, tower, plate).

Once typological classification is defined, we analyze its characteristics from a technological-constructive study.

#### *2.1.2. Technological-constructive classification*

We have recognized two groups in relation to this classification. First, we can find a craft production, which we call *wet construction*, also called heavy construction or traditional construction. Second, we recognize a serial production by industrialization of production processes, which we call *dry construction (assembly)*, also called non-traditional, mostly consisting of lightweight systems. At the same time between wet and dry construction we recognize *mixed processes* which incorporates the advantages of both. These last two types of production (dry and mixed) are not often employed in our country; detecting an absolute predominance of wet construction, verified in all defined representative typologies.

When the technological-productive processes were defined, we return to the typologies considered in order to analyze and recognize its basic elements, disaggregated into envelope elements and their joints.

#### *2.1.3. Envelopes elements and their joints*

To go deeper into the study of the morphological and technological-constructive classification of existing building typologies, we separate them into smaller units, proposing a disaggregation of their envelope components. Thus, we defined the variants detected into three main elements: walls, roofs and openings, and their different joints.

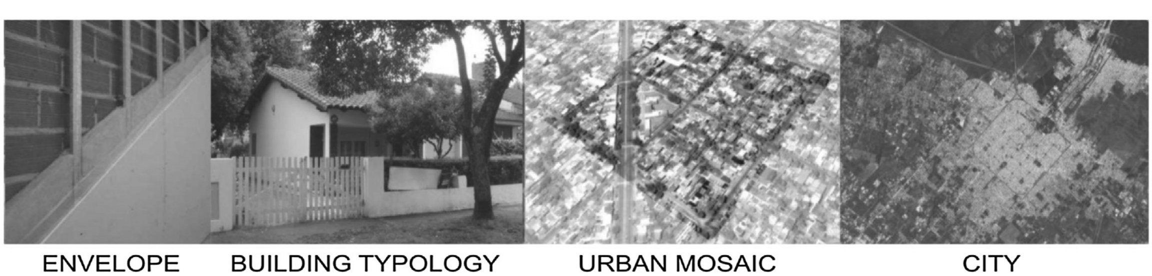



**Fig. 1.** Scales of analysis.

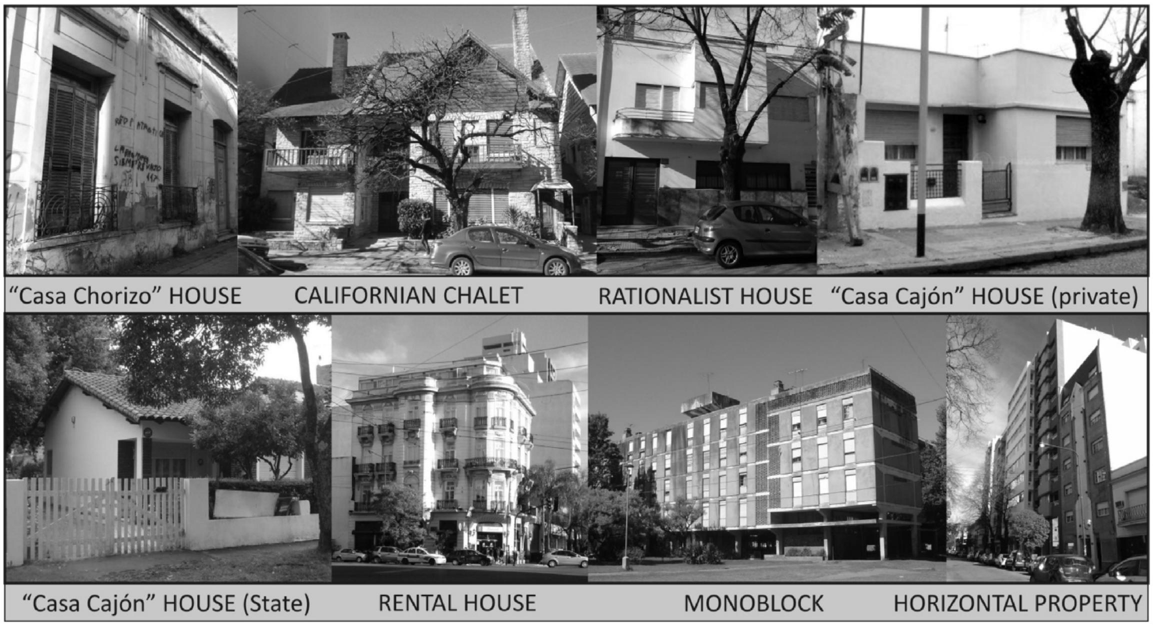



**Fig. 2.** Residential typologies of La Plata.

a) For the element "wall" we detect almost exclusively the ones built with solid clay bricks (or "common brick") and hollow clay blocks, plastered on both sides. Walls built with load-bearing hollow blocks, concrete blocks and double walls with air chamber (Fig. 3) are less representative.
b) For the element "roof", we divide them into tilted and flat ones. As for the tilted ones, we mainly detect corrugated galvanized iron, also French and Spanish tile (Fig. 4). Regarding flat roofs, the most relevant are filled slab, and precast concrete elements (Fig. 5).
c) For the element "opening", we classified them according to: its material and system. The materials detected are: wood, iron sheet metal, aluminium, PVC. The most widely employed systems are: turning, sliding, and fixed glass (Fig. 6). Less frequent: are tilt and turn, guillotine, fold and slide, pivot.
d) From the analysis of the envelope elements we identify 3 main joints (Fig. 7): Roof with wall; Wall with opening; and critical points.

The proposed classification and analysis allows systematization and implementation of a technological-constructive library, and also mitigation measures and their results at building and urban improvement.

### *2.2. Systematization and instrumentation: thermal and economic evaluation of technological-constructive proposals for massive retrofitting and energy storage*

Once analysed and classified the residential existing buildings, we present: i) thermal quality evaluation; and ii) energy consumption and economic costs associated with different retrofitting proposals as energy storage.

### *2.3. Thermal quality evaluation of existing buildings*

The thermal transmittance values are obtained from the calculation method determined by the Argentine Institute of Standardization and Certification (IRAM), which is the maximum relevant authority in Argentina [15]. In order to obtain constructive thermal quality standards that ensure minimum conditions of energy efficiency and habitability, we considered the values required by the Law 13059 of the Province of Buenos Aires. These

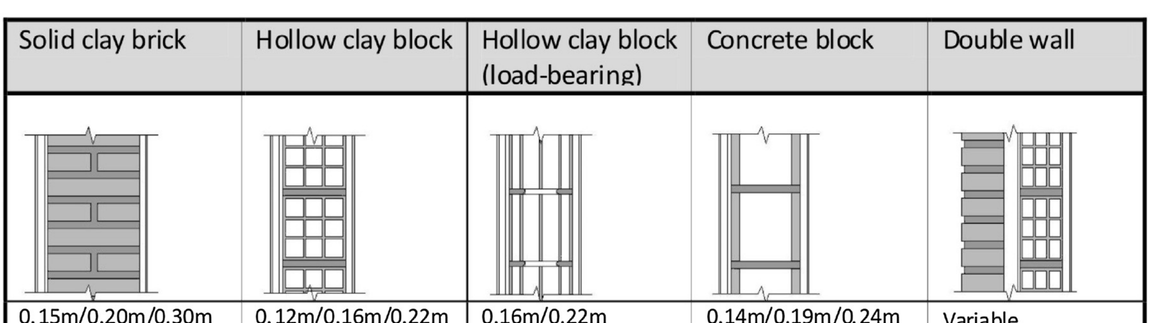



**Fig. 3.** WALL element.

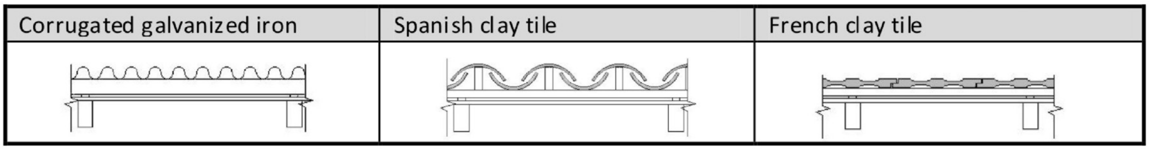



**Fig. 4.** ROOF element (tilted).

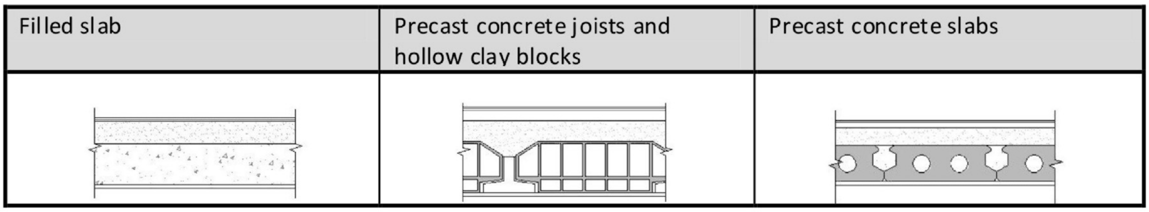



**Fig. 5.** ROOF element (flat).

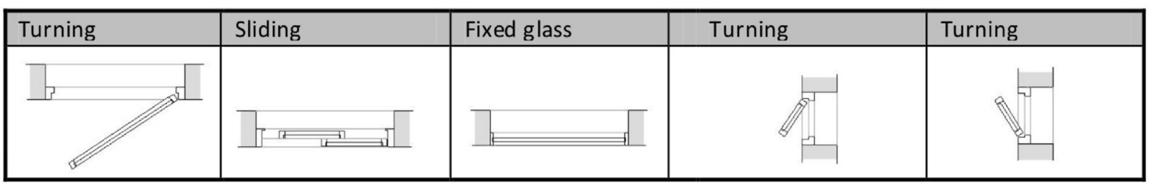



**Fig. 6.** OPENING Element.

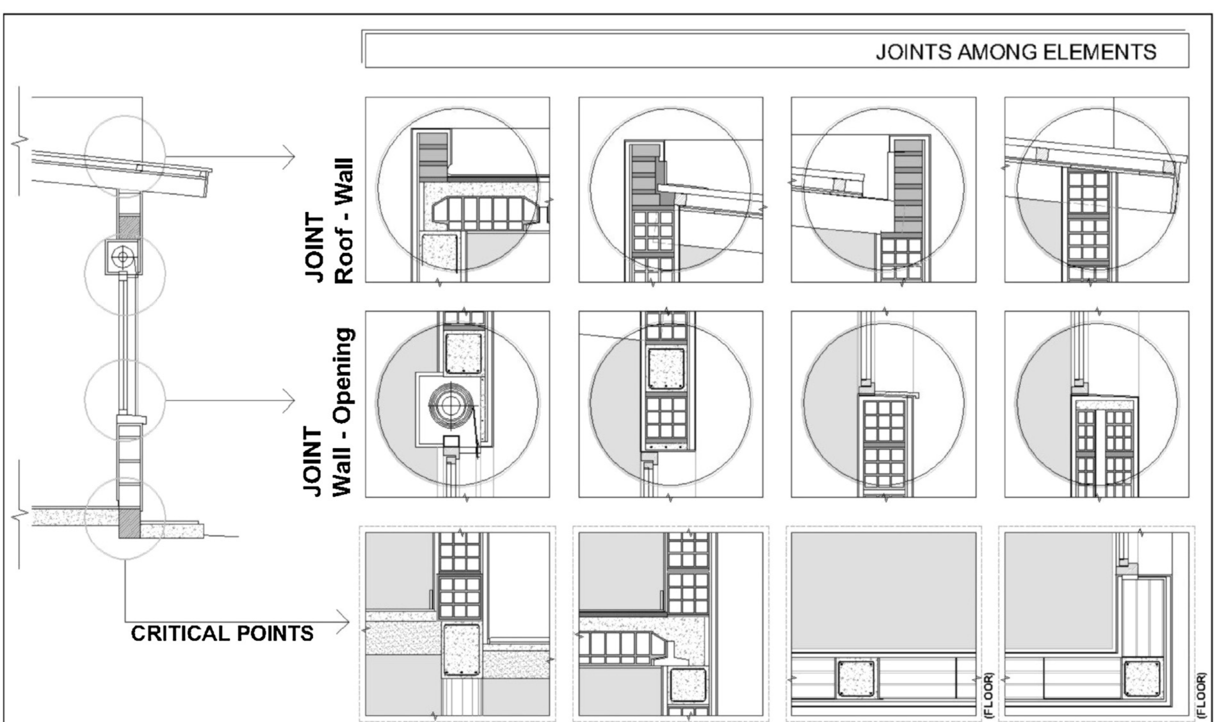



**Fig. 7.** Joints and critical points.

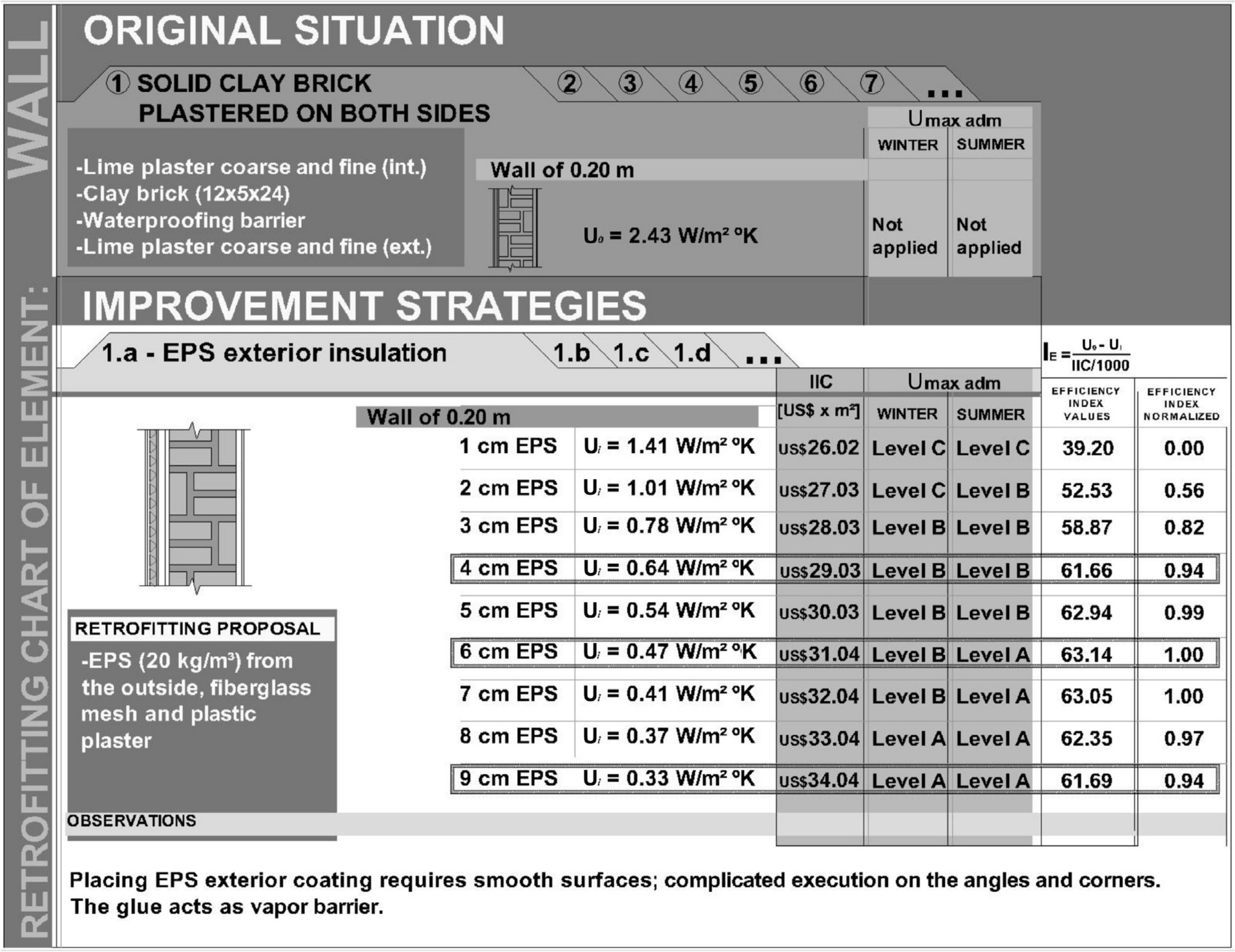



**Fig. 8.** WALL component chart.

are explained in the technical standards of the IRAM referring to thermal conditioning of buildings. These require: compliance to maximum admissible "thermal transmittance" (U) for opaque envelope components (walls and roofs, evaluated for winter and summer conditions) established for levels A or B of IRAM 11605[8]; compliance to maximum admissible "thermal transmittance" for glazed envelope components (openings) established between U4 and U5 category of IRAM 11507-4[9]; and compliance with admissible value of "*global thermal losses coefficient*" (G) according to IRAM 11604. On the other hand we worked on the existing materiality from the theoretical efficiency point of view by defining its thermal physical characteristics. With the application of improvements, thermal efficiencies were analyzed in a theoretically and empirically way in the laboratory through "hot boxes" methods. Dynamic (energy plus software)[10] and stationary (IRAM) energy balances were performed, verifying the base situation theoretically and the improved one in the winter period (annual worst situation).

Considering the values required by IRAM norm, we propose improvement alternatives for each technological building type identified, which are systematized and catalogued in charts synthesized in interactive spreadsheet (excel type) (Figs. 8–10 show a chart example for each element) related to its calculation methodology. The developed system facilitates the loading of the information, adjustment and/or the possibility to make changes dynamically in the study of variants or particularized examples in order to select the most favourable alternatives for each situation.

ii) *Evaluation of energy consumption and economic costs*: To estimate energy consumption for both original and improved housing condition, we employ the analysis from "thermal load" (Q) according to IRAM 11 604 (2001), at steady state. Furthermore we anticipated that the audits are complemented by dynamic simulation methods (by computer), for the purpose of considering not only energy losses but also direct and indirect gains. Anyway, it is necessary to clarify that the main objective of the work lies on the development of the technological-constructive improvement methodology and not on the accuracy of each part.

In this way, the economic costs are obtained from the sum of the "operating cost" (OC) and the "initial investment cost" (IIC). The OC is obtained from the "thermal load" (Q) calculated in relation to the

[8] For walls the maximum admissible value is 1 W/m$^2$ °K; for roofs is 0.48 W/m$^2$ °K.
[9] For openings the maximum admissible value is 4 W/m$^2$ °K.
[10] EnergyPlus is funded by the U.S. Department of Energy's (DOE) Building Technologies Office (BTO), and managed by the National Renewable Energy Laboratory (NREL). EnergyPlus is developed in collaboration with NREL, various DOE National Laboratories, academic institutions, and private firms.

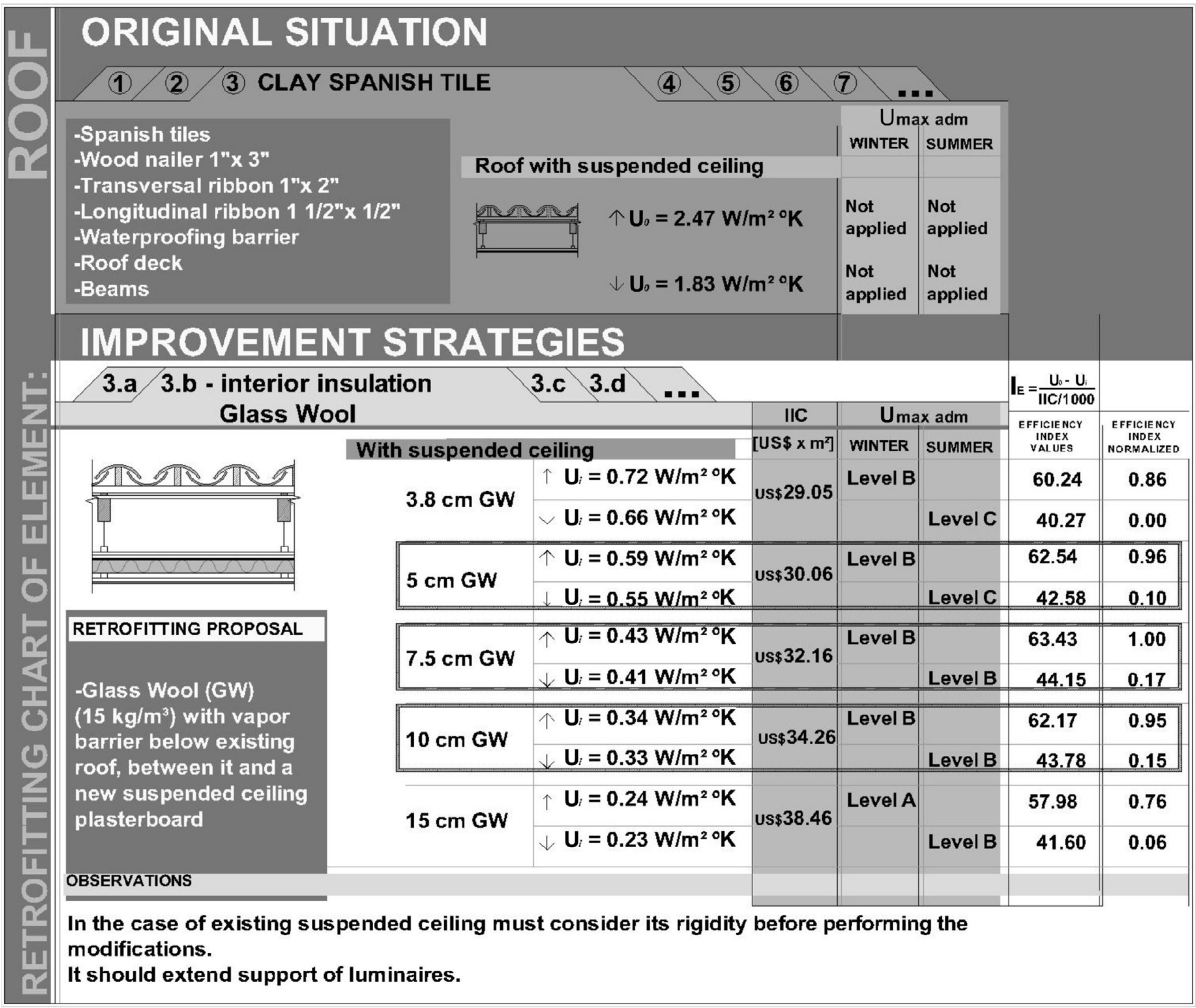



**Fig. 9.** ROOF component chart.

gas cost ($m^2$). And the IIC is shown in the charts as insulation values per $m^2$. These values per square meter are set as the sum of the material and the workforce, based on budgeted values in the local market.[11]

The wide variety of technological-constructive retrofitting alternatives for each element of the envelope determined the need to generate indexes as a complementary tool for implementation of the analysis and selection method. Construction of an "energy-economic efficiency index" ($I_E$) [16] allows us to evaluate each proposed system relating the achieved energy savings (with consequent savings in operating cost), and investment (initial cost) to be classified according to the degree of efficiency on cost-benefit ($\Delta E/\Delta\ \$$). The initial expression includes specific energy flow dissipated per hour in a square meter for a temperature variation of 1 °K, with respect to the cost (in dollars).

$I_E = (U_0 - U_i)/IIC$ (1)

$I_E$: energy-economic efficiency index, W/$m^2$ °K US$;

$U_0$: thermal transmittance value of original situation, in W/$m^2$ °K;

$U_i$: thermal transmittance value of the technological-constructive option adopted, in W/$m^2$ °K;

IIC: Initial investment cost required to implement the technological-constructive improvements, per m2 of building envelope in US$/$m^2$.

Data required to calculate the efficiency index are obtained from the retrofitting charts (Figs. 8–10), to which we incorporated $I_E$ normalized values between 0 and 1 (0 for the worst situation; 1 for the most favorable), in order to facilitate comparison and election of different technological-constructive proposals. Note that this index is proposed as a selection tool, allowing a fast comparison (in relationship between $\Delta E/\Delta\ \$$) in the choice for each envelope element, as well as the selection of the complete proposals (considering all retrofitting alternatives in walls, roofs and openings). Anyway, each selection should also regard other special considerations such as technical difficulties, availability, or difficulties of access to them.

Finally the systematization of the energy consumption evaluation and its monetary costs are presented in its application to urban scale. In this sense, identification and evaluation of buildings typologies in representative areas will reveal the potential of energy saving in different areas of the city, assess energy storage

[11] The costs require updating periodically to achieve greater fidelity in total costs. All values are referenced to the charts, so its modification is automatically reflected in the system update. For this work, the costs are obtained from the publication "Housing" (ISSN 0505-7981), which is updated monthly.

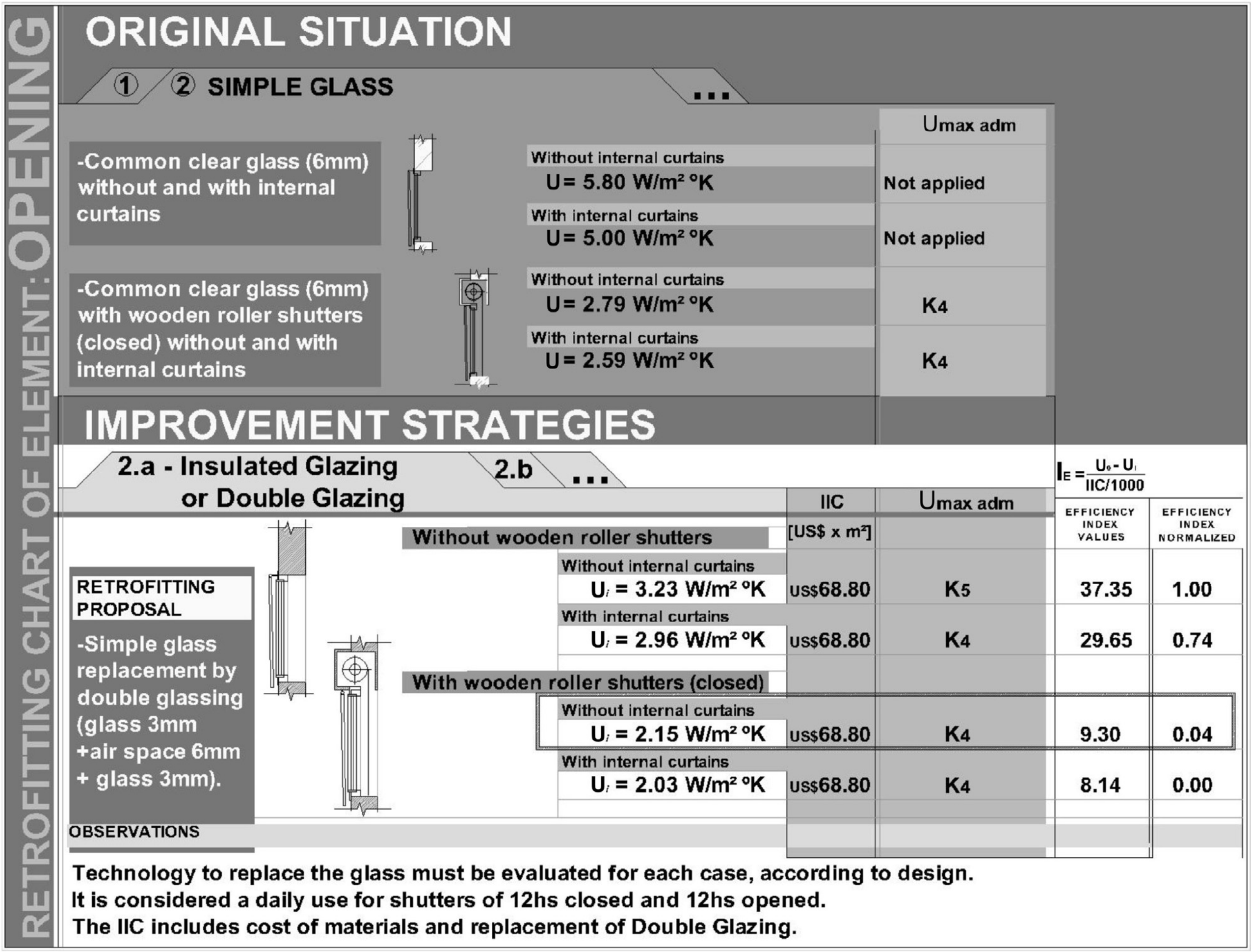



**Fig. 10.** OPENING component chart.

and environmental impacts of the residential sector, and significantly modify the national energy matrix. In order to address this scale of analysis, the concept of urban mosaic is implemented as system of recognition, selection, and urban sprawl, associated with building typologies, energy storage and representative technologies; which allows us to make possible the massive implementation of improvements and to evaluate contrasts between energy savings and economic costs (investment and amortization).

Based on the foregoing and as an exemplification, we propose its application on a representative apartment in La Plata.

## 3. Application example and main results

It is important to remember that the proposed evaluation methodology is applicable to buildings in the different regions of the country (and easily extensible to other regions) from the building considerations set in IRAM. The analysis universe adopted for our research, corresponds to residential buildings in the city of La Plata, Argentina, referenced as bioclimatic zone III: warm temperate, sub b: wet (IRAM 11603); considering its typological diversity with its thermal and constructive variables.

Therefore, we describe the urban area of La Plata according to the study of the representative Urban Mosaics; which are classified into three levels of urban consolidation: high, medium and low. It was estimated that areas of high consolidation represent approximately 2.2% of urban land area of La Plata (169 ha) with 123,156 inhabitants (729 inhabitants per hectare). Medium consolidation areas represent 17.30% (1332 ha) with 154,061 inhabitants (116 inhabitants per hectare); and low consolidation areas represent 80.49% of total (6196 ha) with a population of 377,107 inhabitants (61 inhabitants per hectare) [17]. This first diagnosis recorded a significant dispersion in the urban area.

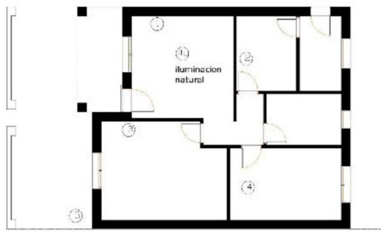
For this work, we will analyze compact houses, being the most representative of our study area [6]. They are mostly located in

**Fig. 11.** Urban Mosaic Study: simplified satellite image and volume.

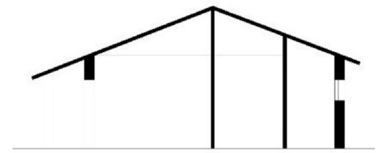
**Table 1**
Characteristics of “casa cajón” house typology adopted.

”Casa Cajón” HOUSE CHARASTERISTICS


EXTERIOR PHOTO



FLOOR


SECTION

| | |
|---|---|
| Volume | 185.20 $m^3$ of interior volume. |
| Area | 60.14 $m^2$ of interior surface |
| Perimeter | 32.02 m. |

Constructive technology of envelope in original condition

| Element | technological-constructive characteristics | Area |
|---|---|---|
| Wall | Plastered brick: Load-bearing wall of solid clay brick (0.20 m). Lime plaster on both sides with waterproofing barrier. | Exposed = 65.99 $m^2$<br>Unexposed = 25.1 $m^2$ |
| Roof | Spanish Tile: with wooden supporting structure. Suspended ceiling plaster. | Exposed = 63.55 $m^2$ |
| Opening | Common glass windows: wooden frames. Wooden roller shutters. | Exposed = 5.42 $m^2$ |
| | Exterior wood door: with metal frames. | Exposed = 3.36 $m^2$ |
| Floor | Subfloor on natural ground. Ceramic. | Unexposed = 60.14 $m^2$ |

medium consolidation areas. Morphologically, these areas are reflected by the urban mosaic shown in Fig. 11. For further analysis we performed fieldwork in order to estimate typological representativeness. We detected a predominance of 41.2% from compact houses of one floor, recognized on “casa cajón” typology (disaggregated into: 21% with corrugated iron roofs, 18.7% with ceramic tile roofs, and 1.5% with slab). While compact typologies of two floors represent 14.6%. The little compact houses represent 12.7%. And “other” types such as shops or warehouses represent 31.5% of the survey studied mosaic.

For the application of the methodology developed we selected a specific one story compact house, known as “casa cajón” house (Table 1), being the most representative typology in our sector (41.20%). We propose the comparative evaluation of original condition and three retrofitting proposals. The steps are: a. Thermal quality evaluation; b. Energy consumption and economic costs evaluation using the calculation of the efficiency index.

### *3.1. Thermal quality evaluation*

Based on the determination of technological-constructive characteristics of the envelope (according to IRAM) we obtained thermal transmittance values “U” (both original and improved). For the analysis of each element, the retrofitting charts are employed (Figs. 8–10). From these values, we calculate the “*global thermal losses coefficient*” (G) as volumetric indicator (Table 2), which allows us to make estimations of heating thermal loads for each case.

Strategies adopted in our example application are: for the “wall” element, the addition of insulation with exterior application technology in 4 cm, 6 cm and 9 cm EPS thickness (according to the technological-constructive proposal (Fig. 8)), avoiding reducing the dimensions of the interior spaces, and incorporating thermal mass for living conditions. $I_E$ values for these walls are 0.94 (61.66 kW/m ºK US$), 1.00 (63.14 kW/m ºK US$) and 0.94 (61.69 kW/m ºK US$) respectively. For the item “roof” we incorporated insulation from inside, simplifying installation, with 5 cm, 7.5 cm and 10 cm glass wool (GW) thickness, (according to the strategy listed in the appropriate chart (Fig. 9). $I_E$ values for these roofs are 0.96 (62.54 kW/m ºK US$), 1.00 (63.43 kW/m ºK US $) and 0.95 (62.17 kW/m ºK US$) respectively (for the rising air flow). Criteria for the selection of these thicknesses correspond to the adoption of $I_E$ optimal value (1.00). The election of these alternatives with similar values to each other (0.94 and 0.94 for

**Table 2**
Envelope thermal quality of “casa cajón” typology adopted.

Thermal quality of envelope in original and improved condition

| Element | Characteristics Original | Characteristics Proposal 1 | Characteristics Proposal 2 | Characteristics Proposal 3 |
|---|---|---|---|---|
| Wall | Plastered brick<br>U = 2.43 W/$m^2$ °K | Original + 4 cm of EPS<br>U = 0.64 W/$m^2$ °K | Original + 6 cm of EPS<br>U = 0.47 W/$m^2$ °K | Original + 9 cm of EPS<br>U = 0.33 W/$m^2$ °K |
| Roof | Spanish tile<br>U = 2.47 W/$m^2$ °K<br>1.83 W/$m^2$ °K | Original + 5 cm of GW<br>U = 0.59 W/$m^2$ °K (w.)<br>0.55 W/$m^2$ °K (s.) | Original + 7.5 cm of GW<br>U = 0.43 W/$m^2$ °K (w.)<br>0.41 W/$m^{2}$ ⁰K (s.) | Original + 7.5 cm of GW<br>U = 0.34 W/$m^2$ °K(w.)<br>0.33 W/$m^2$ °K (s.) |
| Opening | Simple glass with wooden shutter<br>U = 5.80 W/$m^2$ °K<br>2.79 W/$m^2$ °K | Incorporation of IG<br>U = 3.23 W/$m^2$ °K<br>2.15 W/$m^2$ °K | Incorporation of IG<br>U = 3.23 W/$m^{2}$ ⁰K<br>2.15 W/$m^2$ °K | Incorporation of IG<br>U = 3.23 W/$m^{2}$ ⁰K<br>2.15 W/$m^2$ °K |
| Global termal losses coefficient (G): Maximun admisible value Gadm = 1.75 W/$m^{3}$ ⁰K | | | | |
| G calculated | 2.96 W/$m^3$ °K | 1.67 W/$m^3$ °K | 1.56 W/$m^3$ °K | 1.48 W/$m^3$ °K |

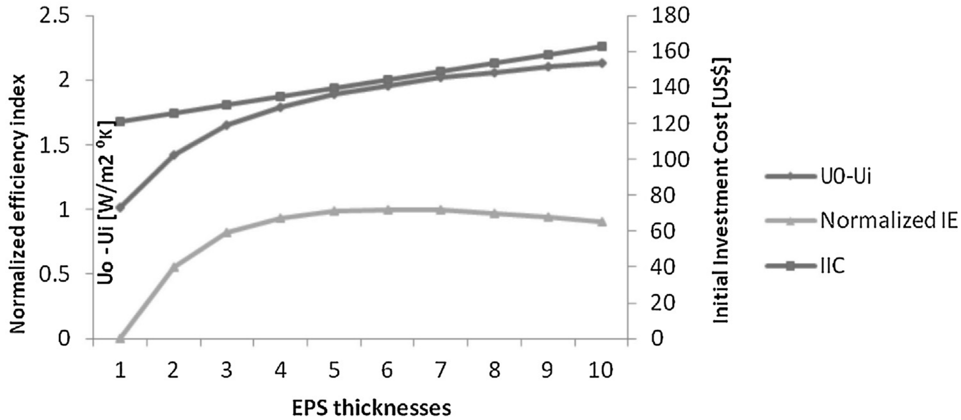



**Fig. 12.** Energy-economic Efficiency Index (IE) and its relationship between thermal transmittance values (Uo – U) and Initial Investment cost (IIC).

**Table 3**
Comparison of thermal loads for heating.

| Annual thermal load for heating "Q" with base temperature of 20 °K | | | | |
|---|---|---|---|---|
| | Original | Proposal 1 | Proposal 2 | Proposal 3 |
| Thermal load [KJ] | 79120151 | 44549035 | 41558529 | 39448632 |
| NG consumption [m3][a] | **4050.65** | **2280.74** | **2127.64** | **2019.62** |

[a] It is considered an equivalence of 1 $m^3$ NG = 9300 kCal = 38,130 KJ.

wall, 0.96 and 0.95 for roofs), close to 1.00, allows us to compare advantages and disadvantages of the different variants, as well as their differences compared to the optimum. For item "openings" simple glasses are replaced by Insulated Glazing (IG) or double glazing for all cases. Table 2 summarizes the Proposals and their thermal transmittance values.

For the selection of each retrofitting proposal the relationship between cost and energy savings are analyzed, for which we employed, as a pre-selection tool, the efficiency index ($I_E$) proposed. As an example we present the analysis for the element "wall". Fig. 12 summarizes the values as a result of the calculation of $I_E$ in a disaggregated way, in order to analyze their behavior on the incorporation of different insulation thicknesses.

Fig. 12 allows us to determine efficient intervention ranges (theoretically) for energy storage; determining minimums insulation thickness employed for wall element. It also determines the inflection point where the addition of insulation as investment ceases to provide significant savings. The same logic applies to all technological-constructive proposals identified.

### *3.2. Evaluation of energy consumption and economic costs*

In this case, we adopt a base temperature of 20° K for the calculation of energy consumption (according to the values established by IRAM). As energy source, we use balanced flue heaters by natural gas (NG), being the predominant technology in the study area and in Argentina, with a representation of the 85% of households connected to the natural gas system [18].

Table 3 presents auxiliary energy values required for original and improved options, as thermal loads and as annual natural gas consumptions; being affected by the heaters performance, considered in order of 50%.

According to the estimated thermal loads and energy storage, consumption reductions of 43.69% are manifested for the proposal 1; 47.47% for the proposal 2, and 50.14% for the proposal 3. These estimations as a theoretical modeling are located in an acceptable range of accuracy in relation with empirical measurements in similar cases in our context [4,6,19].

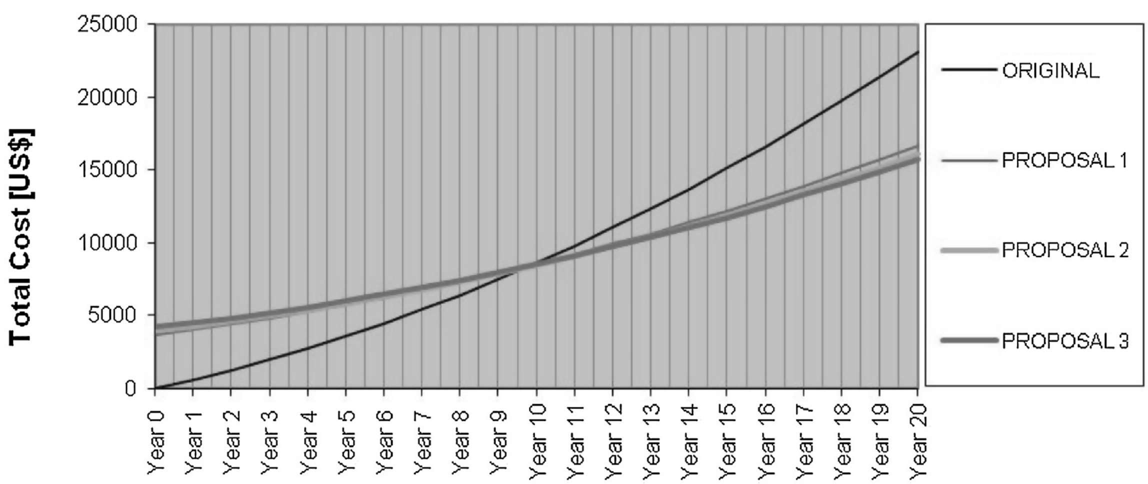



**Fig. 13.** Diagram of technological-constructive costs for "casa cajón" house.

Fig. 13 shows the economic costs evaluation of "casa cajón" house, with the cumulative cost of the original situation and proposals. These costs are obtained from the sum of the "initial investment cost" (taken from the charts of Figs. 8–10), plus the "operating cost" (obtained from the analysis of thermal load, previously mentioned); which are affected by a constant annual inflation rate of 11%, established by the National Institute of Statistics and Census of Argentina (INDEC).[12]

In order to obtain the "operating cost", the value of Natural Gas (NG) fuel is estimated at US$ $0.11/m^3 + 35\%$ tax, which was calculated as an average value between subsidized cost and imported NG cost, for residential category [20] with annual consumption higher than $1500\,m^3$, according to the service distributor (Camuzzi Gas Pampa S.A).[13]

According to the cost evaluation expressed in Fig. 13, the three retrofitting proposals amortize the initial investment over an approximate period of 10 years, (considering the continuity of current subsidy policies); providing better habitability conditions since the beginning of intervention. In this sense, the proposed implementation allowed us to verify a range of thickness for energy storage (quickly detected by the use of $I_E$) which have similar benefits; considering that for final choice of technological-constructive options costs and consumptions must be included, but also other factors such as availability, implementation, habitability conditions, habits and customs of the inhabitants.

As a last step in the development of the proposed methodology, we integrate the results in an urban mosaic to evaluate energy storage values of mitigation measures applied to the selected typology. In this way, we consider that if the proposed improvements for "casa cajón" house typology are performed to all units present in the mosaic (which represent 41.20% of the households (Fig. 11)), we will obtain a reduction of energy consumption achieved around 20% in the residential sector under study.

## 4. Conclusion

This paper summarizes the guidelines of a methodology for energy optimization of the residential sector which proposes a proper use of energy storage technologies applied to massive retrofitting. The selection of technological-constructive strategies aimed at reducing energy consumption of existing residential buildings, enables improving indoor habitability. The implementation of the energy storage in residential dwellings for each particular housing and for its reproduction to massive scale is systematized; assuming that it will provide significant benefits in the urban sector involved: improving habitability conditions (in which the total of the selected representative typologies are below the minimum required by law 13059); and modifying significantly the national energy matrix. Therefore we believe that the proposed actions are necessary to carry on massive retrofitting and optimization of existing envelopes, understanding that the additional investment cost for energy storage is amortized in: i. an immediate improvement of interior comfort; ii. lower operative costs, and iii. a decrease in initial investment by the possibility to install less powerful equipment.

We understand that the proposed work produces a significant contribution in the energy storage concept based in the instrumentation of the methodology to determine selection criteria of technological-constructive retrofitting strategies, promoting its implementation in a systematic and massive way at urban scale. The viability of the technology options is based on the relationship among habitability conditions, practical determinants of energy storage context, and the complement between savings and costs for such purposes. In this sense, the proposed relationship from "energy-economic efficiency index" facilitates the election, determining a hierarchy of efficiency.

Regarding the application example, it allowed us to recognize and verify the presence of a certain range of insulation thicknesses where incorporation of higher thicknesses does not promote significant savings. This is where the efficiency index allows us a quick verification. Such systematization presents viable retrofitting options within a range that associate the energy efficiency and the costs, helping to choose the best technological-constructive strategies for massive application and energy storage.

In brief, it is verified that the savings potential of the typology allows extending its results to the urban scale and thus replicate improvement proposals promoting a significant reduction in residential consumption considering its envelope as energy storage. According to estimates made in the application example, savings of 20% would be achieved in the sector, noting that the participation of this sector represent almost a quarter of the national energy matrix. This (theoretically) reduction in energy demand is beneficial both for all individual users (who amortized initial retrofitting costs in a brief time), as for the group of the population and the state, because this reduction would allow dispensing with fuel imports and reframing subsidy policies.

[12] This value was estimated for 2012, and we apply it as constant value. http://www.indec.gov.ar 05/06/2013.

[13] http://www.camuzzigas.com/clientes-residenciales.php 05/07/2012.

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