

The residential built heritage of Algiers and its energy behaviour: case study of the building number 3 flats of the Aero-habitat district

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Abstract

This research work is aimed to contribute towards the development of a strategy of energy control for existing built heritage. Two components have been considered to make building designers aware of a building's behaviour towards thermal comfort and energy saving. Two parameters of design and rehabilitation of residential built heritage have been carried out, dealing with an environmental site study and energy saving. An assessment of the thermal losses of the building envelope was made to evaluate the effect of the walls and roof components, before and after rehabilitation, which allowed for the proposal of various solutions relating to the reduction of heat loss in the building. A simulation scenario has been used to reach this objective.

The results obtained enabled us to show that an energy saving rehabilitation would promote the built residential heritage in Algeria.

Keywords: residential built heritage, building envelope, energy rehabilitation, energy saving.

1 Introduction

Our research focuses on the exiting residential buildings, which represent a large part of the built environment and the largest source of energy loss. Interventions in this sector have a significant effect on energy efficiency assessments, which reveal how important the energy saving for this potential is.



The characteristics of residential buildings have an impact on their energy requirements, where the relationship of the volume of housing, the degree of isolation and the exposure to climatic factors are essential. In terms of energy savings, the construction sector comes as a priority for our study.

According to experts of the German company Bayer [1], who hosted a meeting on the topic of energy efficiency on May the 29th 2012 (the German-Algerian Chamber of Commerce), the building sector is the biggest energy consumer, with a share of almost 50% of the total consumption of all types of buildings. As shown below in figure 1, about 60% to 80% of this energy is lost. Air conditioning and heating account for up to 50% of the energy of a home and 60% of heat loss is due to opaque cladding (roofs, walls and grounds). The residential sector accounts for 35% of energy consumption, 58% of which is gas and 61% electricity (MEDENER [2]). This important part of energy consumption in the building sector is also marked by a strong annual growth rate, estimated at 6.28%, which needs to be considered as far as energy saving is concerned for residential areas.

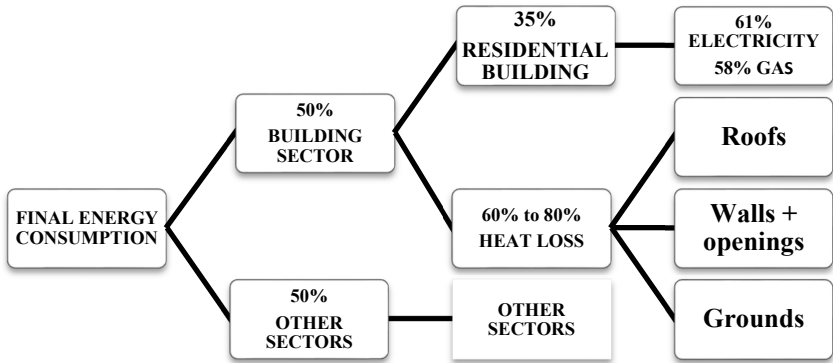


Figure 1: Energy consumption in residential buildings in Algeria.

2 Energy consumption by households

Residential energy consumption is causing significant emissions of greenhouse gases and weighs heavily on the household budget. The retrofit of existing buildings is a priority for many countries around the world, particularly due to the importance of its size and impact. The old buildings are very energy demanding and can represent a number of health risks (Flory-Celini [3]). Reducing energy consumption is a challenge that needs to be considered for socio-economic, environmental and health targets.

Residential building is a major energy-consuming sector. In Algeria, it is responsible for over 35% of energy consumption (Chabane [4]). The development

prospects of housing coupled with the improvement in the rate of household equipment, including air-conditioning and heating, lead to an exponential increase in energy consumption. A prospective study of the evolution of supply and energy demand by 2020 predicts growth in energy demand for the residential sector in the area of 76%, compared to the level of consumption data (NOS [5]).

Saving energy by thermal insulation does not seem to be of major concern in Algeria, which builds about 200,000 residential units per year (MEDENER [2]). In the meantime, this sector is one that consumes a great deal of energy through heating and air conditioning. According to the study carried out by CDER [6] on the newly built housing stock, only 2% are insulated and or partially insulated.

Regarding the existing housing stock, we note the lack of support for energy efficiency aspects in the rehabilitation process. The existing housing in Algeria constitutes a significant economic deposit with regards to its great number (62,98,309 units). As an indication of this, the simulation results of the energy saving achieved on a sample of housing by the National Centre for Energy Studies applied to the Building Research potential (CNERIB [7]) reveals that it is possible to save up to 70% on energy consumption for heating without involving the exterior building envelope (Chabane [4]). In this context, the implementation of an energy efficient concept to control energy consumption in the residential sector is more than an obligation. Two questions are asked to support this work:

- a. Does the residential built heritage in Algeria respect the concept of energy efficiency?
- b. If it does not, how can we improve its energy performance?

According to Joffroy [8], the retrofit of the building corresponds to its improved thermal performance of the envelope, which serves as a heat exchanger between the inside and the outside of the component. It consists of slight modifications, such as an interior insulation, the replacing of windows, etc.

The retrofitting of the building envelope concerns the following three components:

1. The walls: the thermal insulation of the building, inside or outside, depends on the needs of the architectural style of the building to preserve the facade.
2. The floors need thermal insulation for the ground (in contact with the soil), the upper floors and underground floors.
3. Windows are the most sensitive features to heat loss. Their thermal improvements allow energy savings of the order of 10 to 15%, by only replacing the single glazing by insulated one, and resizing of windows dimensions depending on the orientation and climate zone surfaces.

3 Case study: “Aero-habitat” building

The “Aero-habitat” is located in the south-eastern part of the district of T  l  mly and south-west of the city centre of Algiers. It was designed by the French architect Le Corbusier’s followers in 1955.



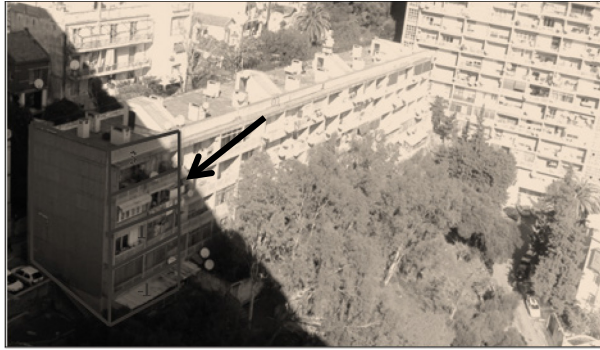


Figure 2: Part of the building considered in this paper [9].

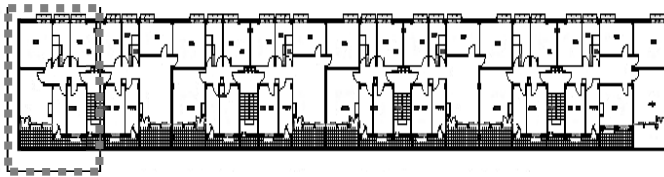


Figure 3: Plan and situation of the considered flats.

3.1 Energy assessment of the building's flats

The apartment is a 120m², F4 type with three bedrooms, a living room, a kitchen, a toilet, a bathroom, a corridor and two balconies.

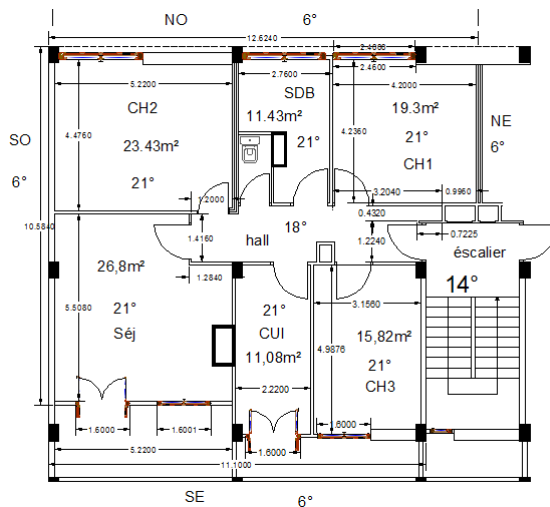


Figure 4: Plan of the apartment on the third floor [9].

3.2 Calculation of the surface transmittance coefficients (U-value)

Heat transmission through the envelope of a flat is the most important source of heat loss. We measured the U-value, which depends on the type of architecture, the type of materials used and the type of insulation. For this case, we used the Algerian DTR method [10] to calculate the U-value for all the concerned components.

3.2.1 The heat balance

The heat balance is used to evaluate the need for heating, as well as all forms of heat losses that are to be evaluated in the apartments.

Heat loss is equal to the outflow of heat by a local heat transfer through the walls.

Total heat loss for the whole flat is given by equation (1) (CDER [6]):

$$D = DR + DP \quad (1)$$

DP = Heat loss through the walls, windows, doors, roofs, thermal bonds.

DR = Heat loss by air exchange, infiltration and openings.

3.2.1.1 Heat loss through the walls The heat loss through the walls is given by the following equation (CDER [6]):

$$DP = DP_{\text{thermal bonding}} + DP_{\text{external}} + DP_{\text{ground}} + DP_{\text{unheated room}} \quad (2)$$

A. Heat loss through the external walls: The heat loss through the walls for the entire rooms is given by the following equation:

$$DP = \sum U_j \times S_j \times (T_i - T_e) \quad (3)$$

S_j = Area (walls + windows + doors + roofs + floors).

T_i = Indoor temperature.

T_e = Outdoor temperature.

U_j = Transmittance.

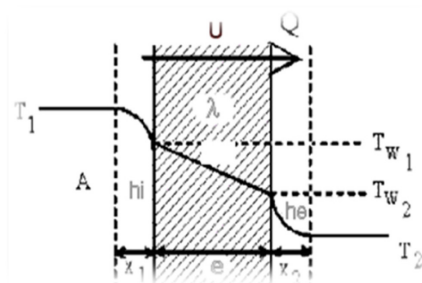


Figure 5: Diagram of heat loss through the walls.

The U-value is given by the following formula (CDER [6]):

$$\frac{1}{u} = \Sigma R + \frac{1}{h_e} + \frac{1}{h_i} \quad (4)$$

ΣR is the sum of the thermal resistances of the various material layers of the wall. (The thermal resistance of a layer, depends on the nature of its material.)
 $1/h_e + 1/h_i$ = the total degree of surface heat exchange.

The transmittance (U) of the glazed walls is given by the following equation:

$$\frac{1}{u} = \frac{1}{v_n} + R_v + R_{rid} \quad (5)$$

$U_{vn} = K$ is the coefficient of the bare glazing ($m^2 \text{ } ^\circ\text{C/W}$).

R_v = is the additional thermal resistance of veiling (if used).

$R_v = 0.025 \text{ m}^2 \text{ } ^\circ\text{C/W}$.

R_{rid} = represents the additional resistance of curtains (if used).

$R_{rid} = 0.03 \text{ m}^2 \text{ } ^\circ\text{C/W}$.

B. Heat losses by transmission through the thermal bonds (LT): It is estimated that heat losses by transmission through the thermal bonds (linear loss) account for about 5–10% of the surface heat losses:

$$DP_{LT} = 0,1 \times DP_{ext} \quad (6)$$

C. Heat loss by transmission through the ground: The heat loss by transmission through the soil is given by:

$$DP_{floor} = U \times S \times (T_i - T_e) \text{ (Mokhtari and Kadri [10])} \quad (7)$$

3.2.1.2 Loss through air renewal For health reasons it is necessary to renew the volume of air of a room, at least once/hour. This causes heat loss that is calculated as follows:

$$DP_{LT} = 0.2 \times DP_{ext} \text{ (Mokhtari and Kadri [10])} \quad (8)$$

DP_{LT} = heat loss by air exchange.

3.2.1.3 The coefficients of surface transmission U Table 1 gives the thermal resistances of superficial exchanges data, for indoor and external walls, ground floors, intermediate floors and roofs.

Heat exchange by radiation and convection with the walls of the two separated areas by the wall, is taken into account in the calculations through a heat exchange coefficient noted superficial and named “h”. This coefficient is expressed in $W/m^2 \text{ } ^\circ\text{C}$.

Table 1: The values of the thermal resistance of the indoor and outdoor, superficial exchanges (CDER [6]).

$1/h(\text{m}^2 \text{ } ^\circ\text{C}/\text{W})$	Wall in contact with: <ul style="list-style-type: none"> the outside an open passageway an open room 			Intermediate wall in contact with: <ul style="list-style-type: none"> room an attic crawlspace 		
Thermal resistance	$1/h_i$	$1/h_e$	$1/h_i + 1/h_e$	$1/h_i$	$1/h_e$	$1/h_i + 1/h_e$
External wall	0.11	0.06	0.17	0.11	0.11	0.22
Roof	0.09	0.05	0.14	0.09	0.09	0.18
Ground	0.17	0.05	0.22	0.17	0.17	0.34

3.2.2 Outdoor walls

Cement plaster thickness = 0.015m, $\lambda = 1.4 \text{ W/m.}^\circ\text{C}$.

Hollow brick Thickness = 0.15m, $\lambda = 0.5 \text{ W/m.}^\circ\text{C}$.

Plaster Thickness = 0.015m, $\lambda = 0.35 \text{ W/m.}^\circ\text{C}$.

$U = 1.91 \text{ W/m}^2.^\circ\text{C}$

3.2.3 The basement's outdoor walls

Cement plaster thickness = 0.02m, $\lambda = 1.4 \text{ W/m.}^\circ\text{C}$.

Reinforced concrete wall thickness = 0.20m, $\lambda = 1.75 \text{ W/m.}^\circ\text{C}$.

Cement plaster thickness = 0.02 m, $\lambda = 1.4 \text{ W/m.}^\circ\text{C}$.

$U = 2.1 \text{ W/m}^2.^\circ\text{C}$.

3.2.4 Indoor walls

Plaster coating layer thickness = 0.015m, $\lambda = 0.35 \text{ W/m.}^\circ\text{C}$.

Hollow bricks thickness = 0.05m, $\lambda = 0.5 \text{ W/m.}^\circ\text{C}$.

Plaster coating layer thickness = 0.015cm, $\lambda = 0.35 \text{ W/m.}^\circ\text{C}$.

$U = 2.46 \text{ W/m}^2.^\circ\text{C}$

3.2.5 Intermediate floor

Coating terrazzo thickness = 0.02m, $\lambda = 02 \text{ W/m.}^\circ\text{C}$.

Cement mortar Thickness = 0.04m, $\lambda = 1.4 \text{ W/m.}^\circ\text{C}$.

Hollow blocks + compression slab, Thickness = 0.20cm, $\lambda = 1.45 \text{ W/m.}^\circ\text{C}$.

Gypsum plaster Thickness = 0.015m, $\lambda = 0.35 \text{ W/m.}^\circ\text{C}$.

$U = 2.46 \text{ W W/m}^2.^\circ\text{C}$

3.2.6 Terrace floor

Coating terrazzo thickness = 0.02m, $\lambda = 2 \text{ W/m.}^\circ\text{C}$.

Draining screed thickness = 0.04m, $\lambda = 1.15 \text{ W/m.}^\circ\text{C}$.

Hollow blocks and compression slab thickness = 0.20cm, $\lambda = 1.45 \text{ W/m.}^\circ\text{C}$.

Gypsum plaster thickness = 0.015m, $\lambda = 0.35 \text{ W/m.}^\circ\text{C}$.

$U = 2.25 \text{ W/m}^2.^\circ\text{C}$.



3.2.7 Ground floor

Terrazzo flooring thickness = 0.02m, $\lambda = 02 \text{ W/m.}^\circ\text{C}$.

Cement mortar thickness = 0.04m, $\lambda = 1.4 \text{ W/m.}^\circ\text{C}$.

Reinforced concrete thickness = 0.20cm, $\lambda = 1.75 \text{ W/m.}^\circ\text{C}$.

Gypsum plaster thickness = 0.30m, $\lambda = 1.20 \text{ W/m.}^\circ\text{C}$.

$U = 1.34 \text{ W/m}^2^\circ\text{C}$.

3.2.8 Doors and windows

Inside wooden framed doors: $\lambda = 02 \text{ W/m.}^\circ\text{C}$.

Outside wooden framed doors: $\lambda = 02 \text{ W/m.}^\circ\text{C}$.

Front door: $\lambda = 3.5 \text{ W/m.}^\circ\text{C}$.

French window: $\lambda = 5.05 \text{ W/m.}^\circ\text{C}$.

3.3 Comparison of results (U) with the French regulation

Due to the missing Algerian thermal regulation, we used the French regulation for the similar climate situation of our case study and the southern part of France.

For the existing buildings (RT existing buildings, published on the 3/05/ 2007), the thermal performance required in the existing habitat zones, situated at an altitude of lower than 800 m and calculated in our case study, is given in the diagram below:

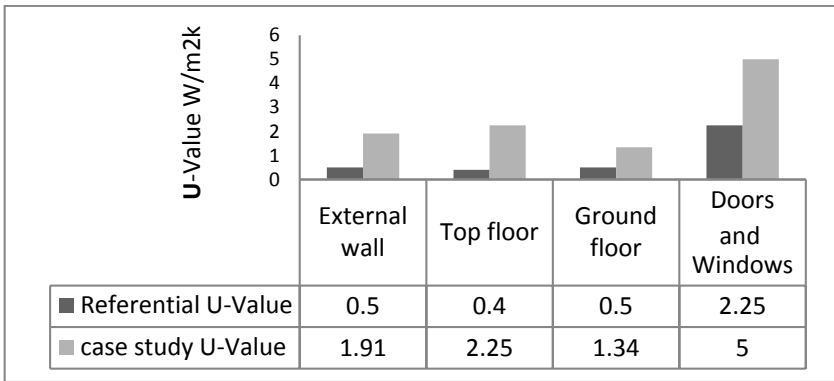


Figure 6: Comparison of the referential U-value to that of the case study.

3.4 Conclusion

The diagram above shows that the coefficients of thermal transmissions of our case study are much higher than those of the French thermal regulation of existing buildings (they are two, three and even four times higher, depending on the type of the walls), it means that the components of our apartments are not economical as far as energy saving is concerned.

3.5 Calculation of the energy balance

To evaluate the energy consumption of our apartments, we calculated the heat loss, to measure the amount of energy consumed during the summer and winter period, and compared them with the building energy saving references. Then we can set the ranking, which allow for fixing the simulations scenario and improves the energy behaviour.

3.6 Results for both summer and winter situations

The interpretation of the calculation results reveals that:

Firstly, the energy consumption in both cases is higher in winter than in summer, which means that heating is the source of the most important energy use.

Secondly, energy consumption in both the winter and summer scenarios is different from one apartment to the other; we noticed that energy consumption is higher in the upper floor apartment than that of the in-between apartment, due to its exposure to the external temperature and its lack of insulation. The apartment situated in the basement is in the same situation even though the consumption is lesser than that of the upper floor apartment, due to the soil temperature, which is lower than that of the external temperature.

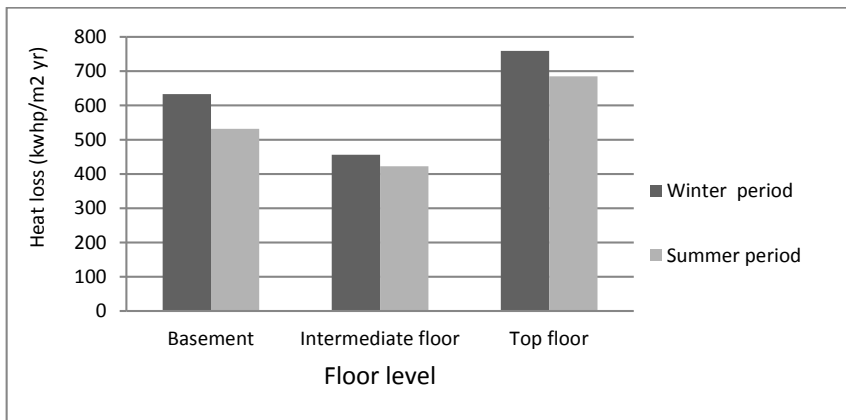


Figure 7: Energy consumption for winter and summer.

After calculating the heat loss of the flats, we compared the results to the energy-saving labels, in order to assess their levels of energy consumption. As it is shown below (in Figure 8), the flats are not designed to respect either the concept of energy saving or the environment. The rate is on G level.

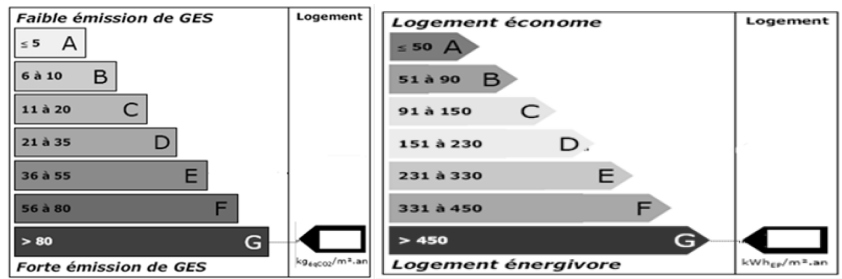


Figure 8: The apartment,energy consumption(Kwhép/m²yr) and gas emission rate of GreenHouse (GHG) in KgeqCO₂/ m² year.

3.7 Discussion

Table 2 shows that all the flats evaluated in both critical seasons are in class G, which means that the flats are at a high level of energy use, with a similar rate of greenhouse gas emission. The results confirm that the heat loss by transmittance is higher than conventionally admitted heat, which means that the energy consumption is too high, whereas, the thermal comfort is critical. The building is not up to standard and it requires energy efficient rehabilitation.

Table 2: Ranking of the apartment's energy consumption related to energy performance labels (for summer and winter conditions).

	Scenario/class					
	Winter period	Summer period		Winter period	Summer period	
Heat loss	Primary energy consumption KWh _{ep} /m².year			Ranking	(Greenhouse effect) Kg _{eq} CO ₂ /m².year	
Second floor	456,20	422,42	G	269,61	249,65	G
Upper floor	759,44	685,23	G	448,83	404,97	G
Basement	633,36	531,57	G	374,32	314,16	G

4 Simulations for improvement of energy behaviour

To evaluate the energy behaviour of the flat's different components, we used an internal insulation system for two reasons:

- A. Firstly, it does not change the outward appearance of the residential building.
- B. Secondly, besides its low cost it does not require a special technique to be fixed.

We also used two different insulation materials for their thermal performance, their availability on the local market and their affordable prices.

4.1 External walls insulation

To adjust the insulation and moisture problems we chose two types of material; polyurethane or rock wool. To fix this insulation, we added to the existing wall, a layer of insulating made of dubbing plaster panels, BA13 ($\lambda = 0.32 \text{ W/m.}^\circ\text{C}$) together with a polyurethane panel or rock wool (thickness 5cm, length 260cm, width 120cm).

4.1.1 Insulation of the basement external side

We only used the extruded polystyrene for this case, due to its thermal and dampness performance. When adding to the existing walls, the setting of this device consists of an insulating layer made of an extruded polystyrene panel and a plastered cardboard panel, ready to be fixed (figure 9).

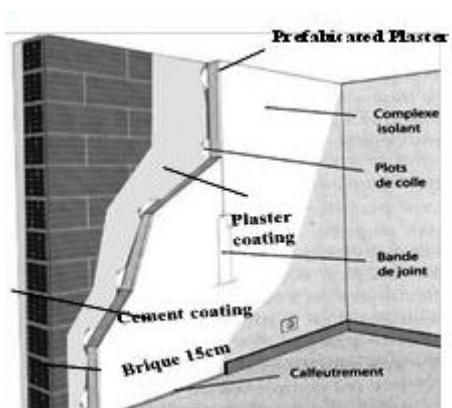


Figure 9: Insulation lining (plasterboard panels BA13 + polyurethane (or rock wool)).

4.1.2 Indoors walls insulation

4.1.2.1 Dry areas wall's insulation For the separating walls of the different rooms, we used double insulation made of plasterboard panels (BA13) and polyurethane (or rock wool) ($12.5 + 40\text{mm}$), of $2.50 \times 1.20\text{m}$. The former is efficient when we need thermal and acoustic characteristics.

The plaster panel is a gypsum core protected by two layers of cardboard, which give strength and smoothness to the wall's surface.

The most common model is the plasterboard (BA 13) 12.5 x 120 x 250cm. Their longitudinal slimmed edges help to fix the panel's jointing.

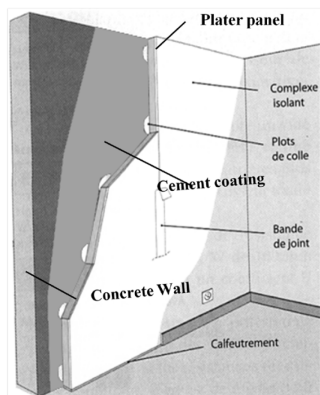


Figure 10: Double insulation (plasterboard BA13 + extruded polystyrene).

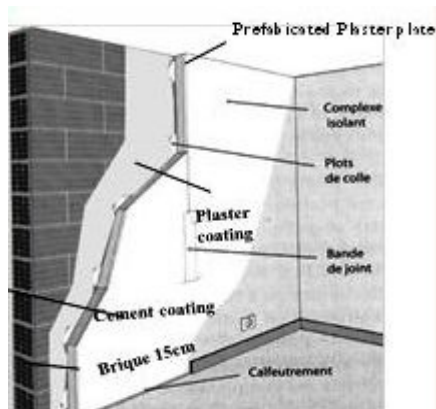


Figure 11: Insulation lining (plasterboard panels BA13 + polyurethane (or rock wool).

4.1.2.2. Isolation of the bathroom and kitchen For the bathrooms and the kitchens, we used panels of plasterboard (BA13-Waterproof 18). The plasterboard waterproofed H1, with two tapered edges and green cladding, works for all types of structures requiring moisture resistance. It is fixed on the inner side of the walls.

4.1.3 Floor insulation

4.1.3.1. Insulation of the ground floor The Floating insulation system is a thermal solution with plastic extruded polystyrene layer. This system provides a high-performance of thermal insulation.

4.1.3.2. The insulation of the intermediate floor For the floor's thermal insulation, we used a floating screed, extruded polystyrene layer. This device is composed of an insulator that is located in the screed force, disengaged from the vertical walls when passing through any other member as the vertical lines by means of insulating strips.

4.1.3.3 Insulation of the terraced roof An extruded polystyrene panel's layer covers the floor's thermal insulation. We used this type of insulation for its resistance to compression stress.

4.1.4 Windows and doors insulation

To reduce heat loss from air transmittance through the windows and doors, we replaced the wooden frames by PVC and aluminium, while a double-glazed window was used to replace the simple-glazed one.

5 Heat loss

5.1 Comparison of results of heat loss and energy for the winter case before and after the thermal retrofitting savings

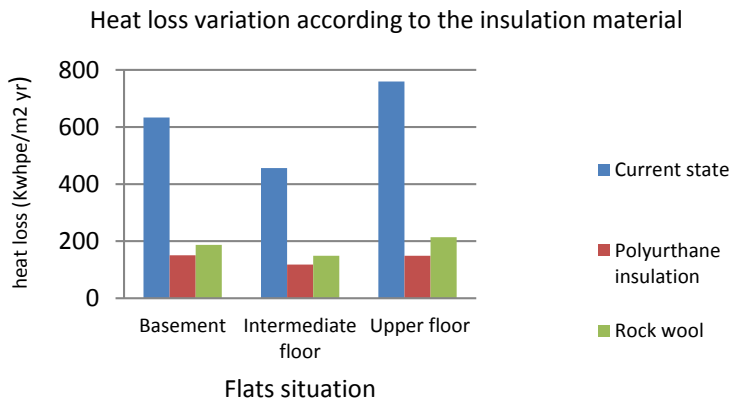


Figure 12: Comparison of the heat loss results of the different flats, before and after rehabilitation.

5.2 Comparison of results of energy saving for different thermal insulation material used

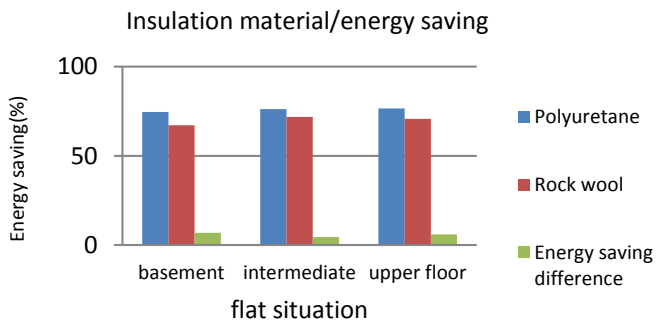


Figure 13: Comparison of energy saving of the different insulations.

5.3 Discussion

The diagrams (Figs 10–13), show the following features:

1. The fixed insulation enabled the heat loss to go down by 70%, compared to the existing state of the buildings' energy behaviour in both summer and winter.
2. The energy saving is higher when the thermal performance of the insulation material (polyurethane and PVC) is concerned. The difference in heat loss between the two solutions for each scenario is about 6% (32 kWh/m².Year) to 12% (64 kWh/m².Year) saved for each apartment.
3. The energy consumption in both scenarios is more important during winter, which demonstrates that the heating demand is the source of high energy consumption.
4. Energy consumption for each period is different from one flat to another.
5. It is higher for the upper floor apartment (182, 33 Kwhep /m².Year) than the intermediate level flat (117.96 Kwhep /m².Year). This is due to the contact with the external floor environment, and its poor thermal insulation.
6. The same case applies to the basement level flat (150.49 Kwhep /m².Year).

5.4 Reviewed classification of the flats' energy consumption, compared to the energy performance labels for both scenarios

According to the energy label, we note that all apartments surveyed at the three different levels of the building number 3 and the two scenarios are found to be in the class C (intermediate flat and basement for summer) and D (top floor); this means that they consume less energy than the initial state, and heat loss is reduced by 70%.

For the climate label, the results show a critical class (F and G), although the emission rate of greenhouse gas emissions is 70% lower.

5.5 Energy consumption calculation of the considered flats

With a polyurethane retrofit (Table 3), we achieved an energy saving of 3950 Kwhep/m².year and a greenhouse gas emissions reduction of 2356.62 Kgeq CO₂/m².year.

With polyurethane and PVC, we can realise a saving of up to 312.38 Kwhep/m².year, higher than that achieved with the rock wool and aluminium insulator material.

Table 3: Energy saved in the flats considered.

Solutions	Polyurethane and PVC		Rock Wool and Aluminium	
Energy savings and GHG emissions	Primary Energy consumption KWhep/m ² .year	Greenhouse gases KgeqCO ₂ /m ² .year	Primary Energy consumption KWhep/m ² .year	Greenhouse gases(GHG) KgeqCO ₂ /m ² .year
3 Flat 2nd Floor	653,33	381,33	592,63	355,03
1 The top floor	1099,22	663,33	1037,44	599,42
1 Basement Flat	890,85	549,28	822,30	463,18
Total	3 950	2 356,62	3 637,62	1062,60

Despite the rather high costs of the insulating material used compared to those of the second solution (window dimensions 115×100 cm, costs €120–500 for PVC and €700–1500 for aluminium, 8cm thick polyurethane insulation costs 22€/m² and a 10cm thickness rock wool insulation costs 12.6 €/m²); the long-term energy saving is more important compared to those costs. We can achieve up to 70% in energy saving. This work showed us the influence of the flats' energy retrofit on the consumption behaviour on the one hand, and thermal comfort on the other. We focused on the choice of comfortable solutions for improving the thermal performance of the building envelope.

The results show that the thermal insulation of the envelope and the type of openings used are among the most effective solutions for an energy efficiency retrofit. Considering only these two components, we realised a 70% reduction in energy use.

Retrofitting has great potential, both in terms of energy and environmental preservation. To obtain a good thermal comfort altogether with energy saving, insulation is fundamental for this type of residential heritage. Finally, this research showed us that an energy retrofit would contribute to upgrading the existing residential building's value.

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