A MULTI-OBJECTIVE OPTIMIZATION APPROACH OF HOUSING IN ALGERIA. A STEP TOWARDS SUSTAINABILITY

Khadidja El-Bahdja DJEBBAR
Lecturer, Ph.D Student, Department of Architecture, Faculty of Technology, Abou Bakr Belkaïd University, Tlemcen-13000, Algeria, e-mail: kh_djebbar@yahoo.fr

Souria SALEM
Professor, PhD, Department of Architecture, Faculty of Architecture and Civil engineering, Mohamed Boudiaf Sciences and Technology University U.S.T.O, Oran-31000, Algeria, e-mail: zinaisalem@yahoo.fr

Abderrahmane MOKHTARI
Professor, PhD, Laboratory of Materials Soil and Thermal, Faculty of Architecture and Civil engineering, Mohamed Boudiaf Sciences and Technology University, U.S.T.O-MB, Oran-31000, Algeria, e-mail: am_mokhtari@yahoo.fr

Abstract. The present study focuses on the evaluation of the energy and environmental performance (EEP) of a typical multi-storey building in Tlemcen, Algeria. It aims to contribute to the development of Algeria's thermal regulation by establishing a list of actions to be taken in short, medium and long term, in terms of thermal rehabilitation in existing housing areas as well as in new ones, in urban regions with a similar climate. An appropriate multi-criteria methodology is developed by determining its thermal performance using a static method as well as establishing a multi- objective strategy of EEP optimization. The assessment of: the potential of primary-energy-saving and that of the CO_2-emissions' reduction and indoor-environmental-quality of a real state of construction by simulation using DesignBuilder software, together with investment-cost are reported. Therefore, this study is conducted using the potential of parametric evaluation methodology to investigate the impact of passive energy-efficiency-measures on the building envelope from energy, environmental, economic and thermal-comfort points of view. Insulation and ventilation reduction are the main measures saving more than 75% of energy and 44% of CO_2-emissions. Besides, the winter comfort is significantly improved. But from the economic standpoint, policy measures must be taken; namely tariffs reforms and energy control law enforcement.

Key words: Multi-storey-buildings, Energy-Performance, Simulation, Passive techniques, CO_2 emissions.

1. Introduction

No society is balanced and in harmony with nature unless housing is sustainable (Armstrong *et al.*, 2005). The residential sector in Algeria is the source of near 43% of final energy consumption (MEM, 2016). Thereby, it has an equally important share in the CO_2 release. The perspectives of Housing Park Development will drive to an exponential increase of this consumption, if the energy control regulation will not be applied. Popular pressure on housing request pushes to quantitative realizations and non-qualitative: total absence of energy efficiency. It is testified by the inefficiency of control and sanctions mechanism and thereabouts even the non-application of the thermal regulation in new buildings which has to become operative from 2005 (Sénit, 2008).

Energy conservation marks a route for extending available energy resources. While Ouahab (2015) has found that, by continuing current trends to 2050, energy consumption in the Algeria's residential sector in the trend scenario could reach nearly 413.4TWh/year, while they are approximately 117.4TWh/year in 2008. This corresponds to a very high growth rate of around 250%. In this scenario, the share of heating would represent 57% of the total consumption, ie 233TWh per year, and that of appliances almost 19% (78.2TWh). Together, these items would total more than 75% of the park's needs. The shares of other uses would remain relatively low: 7% for DHW, 7% for cooling and 10% for cooking.

Overall, the share of energy consumption in the single-family home segment is decreasing in favor of multi-family units. It would rise from 66% in 2008 to almost 62% in 2050. The share of housing in multi-storey-buildings would rise to more than 17%, compared with only 9% in 2008.

As regards the evolution of CO_2 emissions, it has been found that emissions would increase at the rate of the increase in energy requirements, since they would increase by more than 270%, ie 112.7MtCO_2, compared to 2008 emissions (30.6MtCO_2). The average per capita emissions would reach the equivalent of 2.1tCO_2/capita in 2050, while they were only 0.9tCO_2/capita 2008 (Ouahab, 2015).

It thus discharges the importance of regulatory measures relative to thermal performances of buildings as well as the need of detailed studies specific to each context. In fact, many studies have been elaborated at international, regional and local scale to improve EEP of existing housing buildings. All these studies aim to help to make decisions for choosing the appropriate combination of passive and active measures. Methods and energy-saving effectiveness vary from a study to another.

The most used methods assess the building performances on energy aspects, others multi-criteria-methods evaluate most widely the environmental impacts: a) Benchmarking» (Tereci *et al.*, 2013); b) Follow up of consumption to a reference year (Shorrock and Dunster, 1997; Boardman *et al.*, 2005); c) Audits (energy and environmental) (Belpoliti and Bizzarri, 2015; Terés-Zubiaga *et al.*, 2015); d) Post Occupancy Evaluation (Elsharkawy and Rutherford, 2015); e) Life cycle analysis method (Hamdy *et al.*, 2011; Jaber and Ajib, 2011; Huang *et al.*, 2012; Ramesh *et al.*, 2012; Berggren, 2013; Junghans, 2013; Lewandowska *et al.*, 2013); f) Ecologic footprint (Konstantinou and Knaack, 2011); g) Experimentation or energy simulation using parametric method to assess the envelope characteristics impact on heating and cooling systems (Yu *et al.*, 2008; Wasilowski and Reinhart, 2009; Awadallah, 2011; Griego *et al.*, 2012; Charde and Gupta, 2013; Oropeza-Perez and Østergaard, 2014; Belpoliti and Bizzarri, 2015).

The state-of-art and sustainable evaluation of energy efficiency measures (EEM) of residential buildings is usually performed using not only one criterion, but composing several ones (Mikučionienė *et al.*, 2014; Seddiki *et al.*, 2016). The selection of criteria depends on the aim of analysis. The most popular criteria for evaluation of EEM are energy efficiency (EE) or energy saving (Yu *et al.*, 2008; Sun, 2013).

Swan and Ugursal (2009) have provided an up-to-date review of the various modeling techniques used for modeling residential sector energy consumption. Two distinct approaches are identified: top-down and bottom-up. The top-down approach treats the residential sector as an energy sink and is not concerned with individual end-uses. It utilizes historic aggregate energy values and regresses the energy consumption of the housing stock as a function of top-level variables such as macroeconomic indicators (e.g. gross domestic product, unemployment, and inflation), energy price, and general climate. The bottom-up approach extrapolates the estimated energy consumption of a representative set of individual houses to regional and national levels, and consists of two distinct methodologies: the statistical method and the engineering method. Each technique relies on different levels of input information, different calculation or simulation techniques, and provides results with different applicability (Swan and Ugursal, 2009).

For a building in operation stage, heating and cooling requirements intensity, expressed in useful or primary energy (EP) by unity of area (kWh-equivalents/m².year or GJ/m².year), constitute a pertinent indicator of its thermal performances, especially of its envelope (Djelloul *et al.*, 2013).

The energy efficiency criteria are often used together with criteria of environmental impact (EI) and in literature is presented as '2E criteria' (Mikučionienė *et al.*, 2014). Belpoliti and Bizzarri (2015) have used the parametric assessment method in terms of evaluating environmental and energy benefits, deriving from scheduled retrofit actions, to assist technicians in endeavoring interventions priority. Analyzing the outcome data, a simplified parametric calculation protocol has been created to operate a preliminary audit and energy retrofit simulation on the entire social housing stock of the Region Emilia-Romagna, Italy, in terms of both their envelopes and heating system characteristics (Belpoliti and Bizzarri, 2015).

The economical rationality (ER) criterion, as '3E evaluation', is the most used in studies. Shen and Sun (2016) note that there exists an inverted "U-shaped" curve connection between carbon emission, energy consumption and economic development (Shen and Sun, 2016). Tommerup and Svendsen (2006) have given a short account of the technical energy-saving possibilities that are present in existing dwellings and have presented a financial methodology used for assessing energy-saving measures. In order to estimate the total savings potential, detailed calculations have been performed in a case with two typical buildings representing the Danish residential building stock and based on these calculations an assessment of the energy-saving potential is performed (Tommerup and Svendsen, 2006).

Hamdy *et al.* (2011) have proposed a modified multi-objective optimization approach based on Genetic Algorithm and combined with IDA ICE program. The combination is used to minimize the environmental impact and the investment cost for a two-storey house and its HVAC system. Heating/cooling energy source, heat recovery type, and six building envelope parameters are considered as design variables (Hamdy *et al.*, 2011). Ouyang *et al.* (2011) have developed a method demonstrated by a case study. A suitable energy-efficient renovation plan is put forward, integrating all effective and available energy-saving measures, for the subject building and its effects on reduction of energy consumption, CO_2 emissions and cost are evaluated accurately in China (Ouyang *et al.*, 2011).

Popescu *et al.* (2012) have applied methods that quantify the added value due to energy performance, including recommendations on how they can be incorporated in the financial analysis of investments in weatherization. Case studies on some existing condominiums from Romania are analyzed and provide evidence to the research question (Popescu *et al.*, 2012). Missoum *et al.* (2014) have analyzed the energy performance of rural housing built in the district of Chlef, Algeria, for the three construction programs, besides study their impact on the overall energy balance in this district, through tow means: Passive mean by integrating a set of EEM and active one using solar PV for electricity (Missoum *et al.*, 2014). An economic study has been presented but which is not truly realist concerning the EEM cost. Arumägi and Kalamees (2014) have analyzed the energy consumption and potential energy saving basing on field measurements, computer simulations and economic calculations. The renovation packages were compiled using different insulation measures, HVAC solutions and energy sources (Arumägi and Kalamees, 2014).

The thermal comfort (C) or indoor-environmental-quality (IEQ) is also widely used. Carlucci and Pagliano (2013) have optimized the building with the objective to maximize the thermal comfort of the users. They applied a method to design a new net zero energy building, analyzing a set of passive measures (insulation and windows performance). Their objective was to reduce the heating and cooling demand through the comfort improvement (Carlucci and Pagliano, 2013). Liu *et al.* (2015) have evaluated both the indoor environment and energy use of the retrofitted building in comparison with a similar non-retrofitted building from the same area. The case study is a multi-family building which represents common type of construction in the city of Linköping, Sweden (Liu *et al.*, 2015).

Sun and Leng (2015) have investigated the typical indoor environment in Tibetan residential dwellings. Tibetan architectural features and ethnic customs are taken into account in the creation of passive renovations that are applied with minimal effect on the overall architecture. Numerical simulations of the indoor thermal environment are conducted on the building models using DeST-h. Different renewal measures are evaluated in terms of how much they decrease annual energy consumption. Orthogonal experiments are designed to optimize an array of energy-saving building renovations to reduce energy consumption and improve indoor thermal comfort of Tibetan residential houses. The conclusion is that there are economic and environmental benefits of using natural passive methods without considering mechanical ways (Sun and Leng, 2015).

Ortiz *et al.* (2016) have presented a detailed method to develop optimal-costs studies for the energy renovation of residential buildings in Barcelona and Tarragona, Spain. The method allows improving the interaction between the occupancy and the building, and the characterization of the real state of the construction. In addition, the building simulation includes vernacular strategies of the Mediterranean architecture through two-steps evaluation considering thermal comfort, energy and economic criteria (Ortiz *et al.*, 2016).

Environmental and energy efficiency criteria are usually met with Life cycle analysis (LCA). Mikučionienė *et al.* (2014) have defined and analyzed the five main criteria for EEM evaluation reflecting sustainable attitude (energy efficiency, environmental impact, economical rationality, comfort and duration under Life Cycle point of view (LCD)). Sequential prioritization and distribution of decision tree is formed for distribution of EEM to the basic and additional energy efficiency measures. The presented method optimizes the formation of packets of EEM (Mikučionienė *et al.*, 2014). Lawania and Biswas (2016) have assessed the high greenhouse gas (GHG) emissions and embodied energy (EE) consumption associated with the construction and use of a typical house in Perth for sixty building envelope options using a life cycle assessment (LCA) approach (Lawania and Biswas, 2016).

Multi-objective optimization, as its name implies, is the process of systematically and simultaneously seeking one or more best solutions with respect to two or more objective functions. Multi-objective optimization problems are fundamentally different from single objective optimization problems. Single-objective optimization identifies only one globally optimal solution. However, multi-objective optimization problems often involve multiple competing, conflicting and incommensurate objectives (Wu, 2016).

Gossard *et al.* (2013) have adopted a methodology that couples an artificial neural network and the genetic algorithm NSGA-II to reduce the computational requirements of a dwelling for two French climates, Nancy (continental) and Nice (Mediterranean). The optimal solutions are compared to those from mono-objective optimization by using an aggregative method and a constraint problem in GenOpt. The comparison clearly shows the importance of performing multi-objective optimization (Gossard *et al.*, 2013).

This partial inventory allows demonstrating the interest of our demarche which enrolls in a universal scientific effort. As, it demonstrates the absence of specialized and deepened studies at local level therein as well as the absence of a holistic approach of a sustainable evaluation of EEP of residential buildings suitable to Algerian and Maghreb's context. The choice to simulate only the passive measures reveals judicious, that attests the similar results observed in the scientific studies named.

So, the originality of this study, which is a part of a project that analyses different envelopes of multi-storey buildings at Tlemcen, involves the analysis of EEP of a typical dwelling in this town using a multi-criteria assessment of available and affordable EEM through static and dynamic methods. By, the definition of the energy-saving potential and that of the CO_2-emissions' reduction to reach the upper performance levels, as well as setting an order of priority to classify actions to take in short, medium and long runs. In order to contend wastage, improve the comfort, reduce negative environmental impact and extend the life cycle of the building.

In addition of the comparison of its consumption with another existent envelope of the same period, by establishing an internal benchmarking and an external one compared to regional regulations. Moreover, we will check the feasibility of these measures in the Algerian context from an economic point of view. This will contribute to the complement of the Algerian thermal regulation and its upgrade. And help to make decision about choosing the appropriate combination of passive measures.

2. Method

To evaluate correctly the EEP of residential buildings at Tlemcen, this paper develops an appropriate methodology:

- Step 1: Field study is a dwelling in multi-storey buildings dating from the post-independence period in Tlemcen town. Collecting documentation on: the selected case study, at the end of a previous study that indicated it as the least efficient case; regular framework of energy control in residential buildings in Algeria; urban population statistics and households energy consumption in this town;
- Step 2: Collecting and evaluating climatic data;
- Step 3: Establishing the thermal balance through static method by simple calculation of thermal losses of a middle apartment and another in top floor, in order to orient the rehabilitation actions. In addition to, checking of their thermal conformity according to regulatory method presented in Regulatory Technical Document DTR C3-2 of 10/12/97;
- Step 4: Establishing a strategy of losses reduction by using an environmental and economical approach concerning the choice of local materials stemming from recycling and by placing those the most ecological inside the apartment and the less ecological ones outside it;
- Step 5: Recalculate the thermal losses of apartments after rehabilitation by performing an external benchmarking by comparing the Algerian thermal regulation to regional ones (Moroccan and Tunisian);
- Step 6: Simulate the energy used by a typical household occupying this apartment by dynamic methods using the couple of « DesignBuilder/Energy plus ». Occupation, building and the characteristics of a real state of the construction is presented later.
- Step 7: Investigate the impact of some passive EEM often used through the improvement of building envelope's elements, as (ventilation, insulation, orientation, greenhouse effect and shading devices) by using the

potential of parametric study in the simulation through tow means:

1) Simulate an active case of the real/actual/existing case before and after thermal rehabilitation;
2) Simulate a passive case of the real/actual/existing case before and after thermal rehabilitation of the optimized case;

- Step 8: Perform a multi-criteria decision making analysis to the rehabilitation according quantitative and qualitative factors (energy-saving and environmental potentials, investment cost, thermal comfort and life cycle duration), by trying to position cases relative to the international label "Low consumption building label BBC (Bâtiment basse consummation)" and the regional one "Tunisian label" (see Appendix A);
- Step 9: Simulate a second envelope dating from the same period of the case study. In order to compare their consumptions and their environmental impacts by establishing an internal benchmarking;
- Step 10: Compilation, synthesis of the collected information and results discussion;
- Step 11: Redaction of recommendations by order of priority in short, medium and long term, in terms of thermal rehabilitation in existing housing areas as well as in new ones.

3. Regular framework of energy control in residential buildings in Algeria

Algeria having adhered at different treaties of climatic changes and environment protection, in sustainable development framework, had to adapt its legislation at the new international context. Since, an ensemble of regular texts, relating to the energy conservation in building, has been adopted. In the 1990 years, Algeria has developed many regulatory devices regarding the energy efficiency in housing. According to a reflection on passive and active consumption of new dwellings initiated in 1995, the National Centre for Studies and Integrated Research of Building (CNERIB) under Housing and Urban Planning Ministry tutelage has led research works and has positioned Regulatory Technical Documents (DTR) in 1997:

- The DTR C3-2 of 10/12/97 which establishes Calculation of Winter Calorific Losses Rules for Housing Buildings (fixing the methods of: calculation of calorific losses of building, checking the conformity of building to the thermal regulation, sizing the heating fixture in buildings) (CNERIB, 1998);
- The DTR C3-4 of 18/08/98 relative to the Rules of Calculation of Summer Calorific Gain for Buildings (fixing the methods of definition of building's calorific gains and the checking method of their conformity to the summer thermal regulation. These DTR have subsequently been approved by Energy and Mine Ministry, and have made, in 2000, the executive decree n°2000-90 object supporting thermal regulation in new housing buildings and others, plus parts of realized construction as existing buildings extension, in the application of the law n°99-90 of 28th July 1999 relative to energy control.
- Also, the DTR C3-31 of 12/04/2006 relative to Natural Ventilation of Housing Usage Areas (fixing the general standards to have to adopt during the conception of natural ventilation fixture, the calculation methods allowing their sizing).

In the extension of the spirit of the law on energy control, the main lines of the national strategy for the control of energy were adopted in 2003. This specifies the articulation of the institutional mechanism intended to ensure a coherent implementation and an optimal use of the main instruments put in place by the public authorities for the control of energy, namely:

- The National Agency for the Promotion and Rationalization of the Use of Energy (APRUE) who has elaborated the National Program for Energy control (PNME). This latter gathers many projects, actions and measures in various fields. The actions concerning building energy efficiency with residential usage are: Thermal Rehabilitation, Energy High Performance Dwellings, Solar Hot Water, High Performance Cooling and High Performance Lighting. 80% of the costs related to these operations will be provided by the National Fund for Energy Control (FNME). In addition of The Intersectoral Committee for Energy Control (CIME), an advisory organ placed beside energy charged Ministry to ensure energy control politic animation and coordination.

4. Energy situation in Tlemcen

4.1. Geography

Tlemcen is located in the extreme north-west of Algeria, exactly at 40km from the Mediterranean Sea as the crow flies, at 63 km from morocco frontier and at 550km far from Algiers (See Figure 1). It is at 1°19' west of longitude, and 34°56' north of latitude and is backed by the flank of lalla Setti's tray of (1200m of altitude). Locally, the agglomeration of Tlemcen extends over the territory of four municipalities (Tlemcen, Mansourah, Chetouane and Beni Mester), covering an area of 2736 hectares populated by more than 236000 inhabitants namely 520h/km² of density. The town site is a sloped plan in South-North direction with variable altitudes between 930 and 550m (Ghomari, 2007).

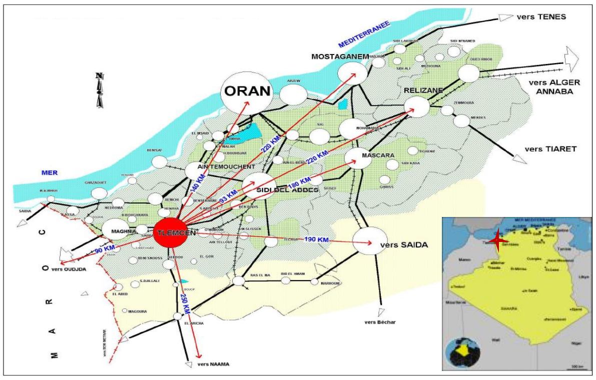

Fig. 1. Tlemcen location: a strategic position in the North-West region (source: ANAT and DUC, 2005).

4.2. Energy situation

According to the data of the year of 2014 provided by the general leadership of National Society for Electricity and Gas (SONELGAZ) of Tlemcen (SONELGAZ, 2015), this province has 252 208 subscribers into electricity and 130 004 into gas. The rate of actual electrification of the province is of 98%. These data testify a noticeable increase of energy consumption from a year to another (see Figure 2).

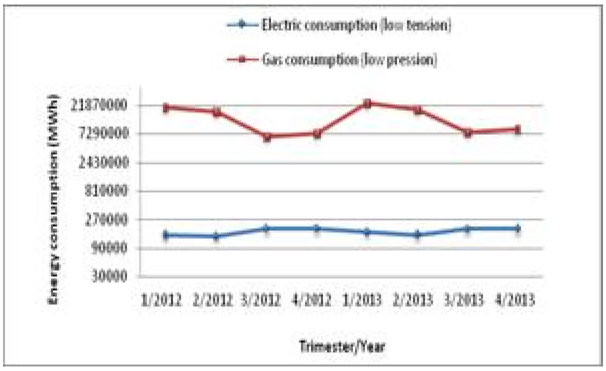

Fig. 2. Evolution of the energy consumption in Tlemcen (source: Author according to SONELGAZ, 2015).

We notice that the number of subscribers increases substantially between the first term of 2012 and the fourth one of 2013, both in electricity and gas (see Figure 3), the number is added of 30 140 subscribers. While, the total specific consumption increase of 3323kWh from 2012 to 2013, pushed essentially by the rise of the specific consumption of the first term of 2013 estimated of 65805kWh compared with 2012. That can be explained by the climate changes.

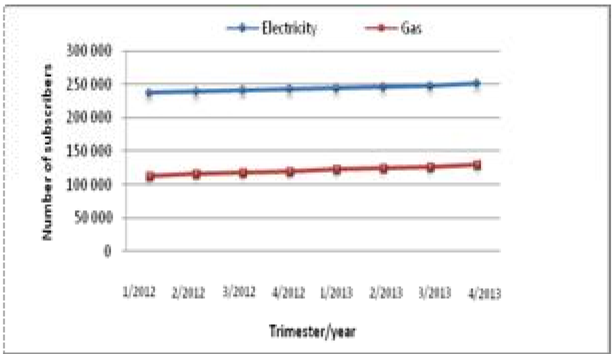

Fig. 3. Evolution of the number of electricity and natural gas subscribers in Tlemcen (source: Author according to SONELGAZ, 2015).

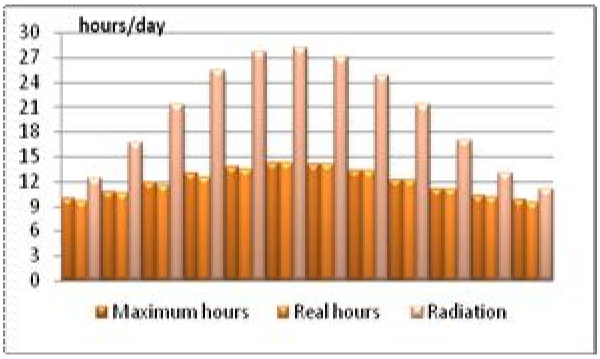

Fig. 4. Sunshine and radiation data on horizontal surface in Tlemcen (source: Generated by Excel Template by author according to O.N.M, 2008).

5. Tlemcen climate

According to the Algerian climatic zoning (CNERIB, 1998), Tlemcen is classified in the zone B. Being on a high altitude, Tlemcen's climate can be cold to very cold in winter and warm to hot in summer, with north-west and south-west winds through the year, and quite a good amount of rain fall. The monthly data of the year 2008 of Safsaf station (at 592m of altitude) in Tlemcen was collected from the National Office of Meteorology (O.N.M) (See Figures 4 to 7).

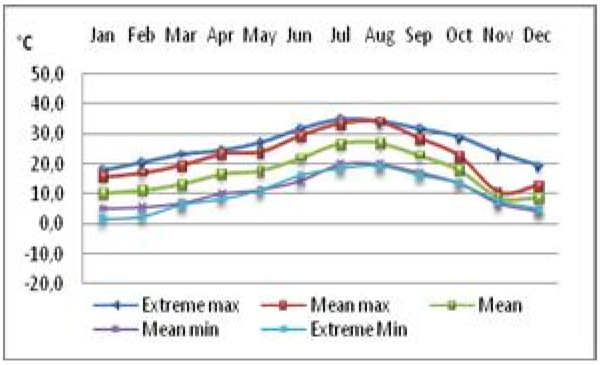

Fig. 5. Temperature data in Tlemcen (source: Generated by Excel Template by author according to O.N.M, 2008).

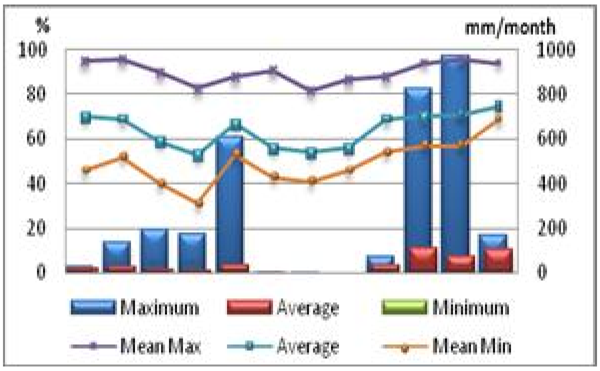

Fig. 6. Humidity and rainfall data in Tlemcen (source: Generated by Excel Template by author according to O.N.M, 2008).

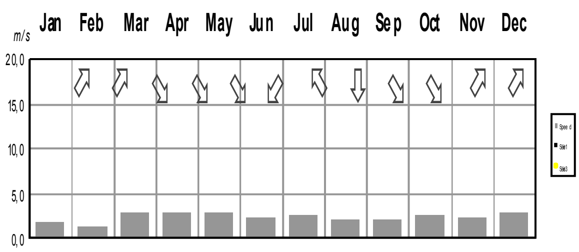

Fig. 7. Prevailing winds in Tlemcen (source: Generated by Excel Template by author according to O.N.M, 2008).

6. Case study

6.1. Description of case study

The case study is located in 1060 dwellings residential district at the East of Tlemcen. It is an apartment with an area of 70.38m² intends for division into living room and 2 bedrooms and a room height of 3.06m. It represents the dwellings constructed during the 1980ies when Algerian politic was oriented toward heavy prefabrication for realization of the great wholes. Thermal and energy analysis is established on a middle corner apartment, with two exposed faces oriented to South-east and South-west compared with another one in the top corner (see Figures 8 and 9). The plan in Figure 10 describes different spaces of the apartment.

Fig. 8. Exterior environment, 1060 dwellings district in Tlemcen (source: Author, 2015).

Fig. 9. Satellite view of 1060 dwellings district in Tlemcen (source: Google Earth, 2012), the photo spot of figure 8 is indicated.

6.2. Building techniques

The buildings in 1060 dwellings district have uninsulated and intight envelopes, and single-glazed windows. Table 1 shows the construction materials which constitute the building envelope.

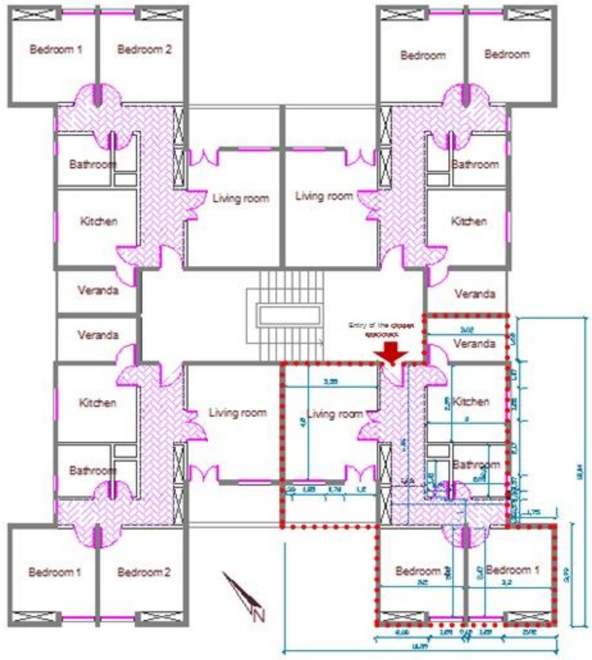

Fig. 10. Apartment plan (source: Author, 2015).

7. Static method

7.1. Simple calculation of calorific losses according to Algerian housing building regulations

Firstly, thermal losses of the case study are estimated by simple state calculation according to DTR C3-2 of 10/12/97, and after regulatory checking, the results in Table 2 have shown that the apartment is not congruent and that the thermal comfort is not insured. Thus to insure the well-being of occupants and to reduce energy consumption, it must be rehabilitated it thermally.

7.2. Design of a personalized strategy

Secondly, we have established a Losses reduction strategy according to the Regulatory Technical Document cited above through recalculating losses by transmission, after reducing them by acting on:

- Insulation of the outer walls from exterior by adding a layer of glass wool of: 1, 2, 3, 4 and 5cm of thickness (as a mineral insulation stem from recycling of broken glass or from the raw material 'sand' which is a local material);

Table 1. Building elements, 1060 dwellings district, Tlemcen (Source: Author according to DTR C3-2).

Building element Layer outside → inside	**Material**	**Thickness (mm)**	**Conductivity W/m.k**	**Specific Heat J/kg.k**	**Density Kg/m³**	**Area m²**	**Thermal resistance (R) m²c°/W**	**Thermal transmittance [a] (U-value) W/m²C°**
External walls	Ciment mortar	20	1.400	1080	2200	80.85	0.0143	3.4083
	Prefab. Concrete panel	130	2.500	1000	2400		0.052	
	Internal Plaster coating	20	0.350	936	1000		0.0571	
External Roof	Gravel	30	0.360	840	1840	70.38	0.0833	0.6042
	Pure Bitumen	15	0.170	1000	1050		0.0882	
	Bitumen, Felt sheet	15	0.230	1000	1100		0.0652	
	Cement sand render	50	1.000	1000	1800		0.05	
	Polyethylene (low density)	0.2	0.35	2300	0.92		-	
	Expanded Polystyrene	40	0.036	1404	20		1.1111	
	Polyethylene (low density)	0.2	0.35	2300	0.92		-	
	Prefab.concrete panel	150	2.500	1000	2400		0.06	
	Internal Plaster coating	20	0.350	936	1000		0.0571	
Intermediate floor	Internal Plaster coating	20	0.350	936	1000	70.38	0.057	2.6525
	Prefab.concrete panel	150	2.500	1000	2400		0.06	
	Cement sand render	30	1.000	1000	1800		0.03	
	Granito tiles	20	2.100	936	2200		0.01	
Internal partitions	Internal Plaster coating	10	0.350	936	1000	-	0.057	-
	Hollowed Brick	100	0.560	936	1300		0.0178	
	Internal Plaster coating	10	0.350	936	1000		0.057	
Partitions face to non-heated spaces	Ciment mortar	10	1.400	1080	2200	14.77	0.0286	3.2499
	Prefab.concrete panel	130	2.500	1000	2400		0.052	
	Internal Plaster coating	10	0.350	936	1000		0.0071	
Windows, glazed doors	Simple clear glazing,	3				11.86	0.1697	1.6260
	Wooden window frame, wooden shutters	30					0.3278	
Doors	Wooden doors	30				3.725	0.5	2

a: calculated by simple state calculation according to DTR C3-2 of 10/12/97

- Insulation of the internal face of the partition which separate the apartment from the non-heated space by adding a layer of cellulose wool panel of:1, 1.5, 2.5, 3.5 and 4.5cm of thickness (as a vegetable insulation stem from recycling newspapers or from the raw material 'Alfa grass' which is a local material) associated to 1.5cm of a plaster panel ;
- Renewing the external roof insulation by maintaining the same insulation material with the same thickness (4cm of extended polystyrene), but by placing the insulation layer over the cope layer not below it;
- Replacing simple glazing with double one (through only elimination of the pane divisors and maintaining the windows frameworks and shutters). In addition of placement of weather strip of windows and doors to reduce air imperviousness;
- Placing of a window with double glazing in veranda and
- Putting awnings as shading devices.

Total thermal losses (D), thermal losses by transmission (D_T) and the thermal characteristics of the existing and the optimum envelopes of the middle and the top corner apartments are given in Table 2. In addition, the regulatory checking to yield the apartment conforms to DTR C3-2.

7.3. Results and discussion

The Results have shown that the Algerian regulation –compared to regional experiences of Tunisia and Morocco- needs to be more thorough, because with first centimeter of insulation, the two apartments become conform. While, just the bold values of surface related transmittance coefficient of external walls verify the maximum allowed heat transfer coefficient at Oujda in Morocco (located at regulative climatic zone ZT3) that has a similar climate with Tlemcen.

Although, Algeria was among the first countries that have elaborated its regulatory framework and has taken part in the elaboration of the Thermal and Energy Regulation of Maghreb's Buildings (RTMB). This later constitutes the starting point of Tunisian label.

Algeria must fulfill the lateness compared with other countries having implemented mandatory buildings thermal regulations as Tunisia and Turkey. In fact, in these two countries, the regulation has been elaborated according to a global process founded on a wide meeting with all participants and associated to the accompaniment programs and the enhancement of the competence of designers, operator and suppliers of insulation materials. Generally, the experience of these countries shows the quality of elaboration process as a key factor of its efficient applicability.

8. Computer simulation

8.1. Base Case

Starting the DesignBuilder simulation, that uses the EnergyPlus dynamic simulation engine (stemming from renowned software BLAST and DOE-2) to generate data performance (see Figure 11), needs to draw plans and elevations of the apartment, for creating building volumes to form the simulated apartment as shown in Figures 12.

For this case, summer and winter were taken as the studied cases. Density is taken 0.07 because the apartment is occupied by 5 persons. The temperature needed for heating in winter was set to 21°C (comfort condition in a housing area in Algeria). The lower temperature limit was set to 19°C. While, the lower temperature for cooling in summer was set to 25°C and the upper one limit 27C°. These inputs are constant for all cases.

Table 2. Results of thermal properties calculations' of envelope components, of recalculation of losses by transmission (D_T) before and after thermal rehabilitation and the regulatory checking (source: Author).

Thermal properties and losses		**Base case No-insulation**	**Outer wall insulation thicknesses**					**Comment**
			1cm	**2cm**	**3cm**	**4cm**	**5cm**	
Thermal resistance (R) m²C°/W	$R_{Ext. Walls}$	0.1234	0.7435	1.0214	1.2987	1.5773	1.8553	Just the bold values verify the maximum allowed heat transfer coefficient of external walls at Oujda in Morocco that has a similar climate with Tlemcen.
	R_{Roof}	1.5149	1,6551					
	$R_{Int Walls}$	0.0877	1.2667	1.3917	1.5167	1.8917	2.1417	
Thermal transmittance (U-value) W/m²C°	U-value $_{Ext. Walls}$	3.4083	1.345	0.979	**0.77**	**0.634**	0.539	
	U-value $_{Roof}$	0.6042	0.594					
	U-value $_{Windows}$	1.626	1.3927					
	U-value $_{Ave.}$ [a]	2.0245	1.3898	1.0753	0.8957	0.7788	0.6972	
	U-value $_{Walls\ n.h.s.}$ [b]	3.2499	0.7894	0.7185	0.6593	0.5286	0.4669	
	U-value $_{Ave.\ n.h.s.}$ [c]	3.7568	0.8651	0.7986	0.7431	0.6206	0.5627	
Coefficient of temperature reduction (T_{au})		0.35	0.60					Given by the DTR
Thermal losses of middle apartment (W/°C)	D_S [d]	300.98	131.39	101.80	84.90	73.90	66.22	
	D_{li} [e]	60.19	26.28	20.36	16.98	14.78	13.24	
	$D_{n.h.s.}$ [f]	21.89	5.96	5.56	5.22	4.49	4.14	
	D_T	383.07	**163.62**	**127.71**	**107.10**	**93.17**	**83.61**	
	D_R [g]	72.89	71.35	71.18	70.84	70.50	70.16	
	D	455.96	234.98	198.90	177.94	163.67	153.76	
Reference losses (W/°C)	$D_{ref.}$	163,42						
Regulatory checking	D_T>1,05 x D_{ref} = 171.59 W/°C		D_T <1,05 x D_{ref} = 171.59 W/°C					The bold values verify the formula
Thermal losses of top corner apartment (W/°C)	D_S	343.5	171.73	141.98	124.76	113.43	105.43	
	D_{li}	68.7	34.35	28.40	24.95	22.69	21.09	
	$D_{n.h.s.}$	21.89	5.96	5.56	5.22	4.49	4.14	
	D_T	434.01	**212.04**	**175.93**	**154.93**	**140.61**	**130.65**	
	D_R	72.89	71.35	71.18	70.84	70.50	70.16	
	D	506.9	283.39	247.11	225.77	211.11	200.81	
Reference losses (W/°C)	D_{ref}	226.76						
Regulatory checking	D_T>1.05 x D_{ref} = 238.1 W/°C		D_T <1.05 x D_{ref} = 238.1 W/°C					The bold values verify the formula

a. Average of surface related transmittance coefficient [W/m².°C]; b. Surface related transmittance coefficient of partition in touch with non heated spaces; c. Average of surface related transmittance coefficient of partition in touch with non heated spaces; d. Surface losses through the current parts of partitions in touch with exterior; e. Losses through the liaisons; f. Losses through the partition in touch with non heated spaces; g. Losses by air renewal.

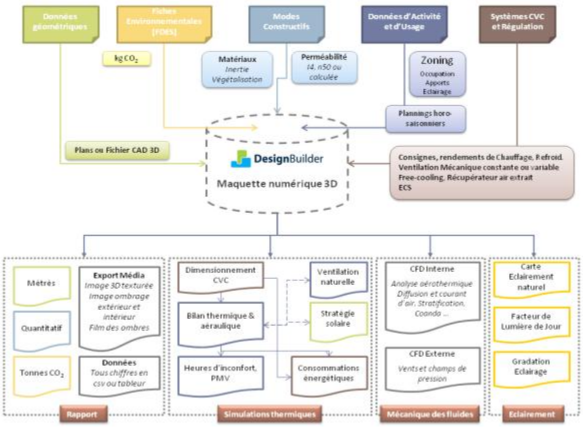

Fig. 11. DesignBuilder diagram (source: DesignBuilder© Software, 2009).

Table 3. Internal loads from five occupants and appliances (source: ASHRAE, 1997).

Volume	Hours	Internal loads (Wh/h)	Comment
1	22-06	300	3 persons sleeping (children)
	10-11	270	Housecleaning for 1 hour
2	22-06	200	2 persons sleeping
	10-12	270	Housecleaning for 1 hour
	14-15	75	1 persons takes a nap
3	07-08	100	5 people passing through
	10-11	270	Housecleaning for 1 hour
	12-13	80	Arrival after work, etc
	18-19	100	5 people passing through
4	06-07	100	Making breakfast for ½ hour
	07-08	550	3-5 people eating and sitting for less than 1 hour
	10-11	270	Housecleaning for 1 hour
	10-12	180	Making lunch
	12-13	440	4 people eating and sitting for 1 hour
	16-17	100	Making cafe for ½ hour
	17-18	330	3 people eating and sitting for less than 1 hour
	19-20	180	Making supper
	20-21	550	5 people eating and sitting for 1 hour
5	10-11	270	Housecleaning for 1 hour
	18-19	265	1 Person showering for ¼ hour
6	08-09	105	1 person sitting for less than ½ hour
	10-11	270	Housecleaning for 1 hour
	15-17	378	2-3 guests sitting
	19-21	400	Living room occupation incl watching TV

Giving the data of personal loads inside each volume at certain times of the day according to the relationship between number of people and the activity that they are doing, the values were applied from (ASHRAE, 1997). Occupation pattern and resulting internal loads of five persons is estimated according to Table 3.

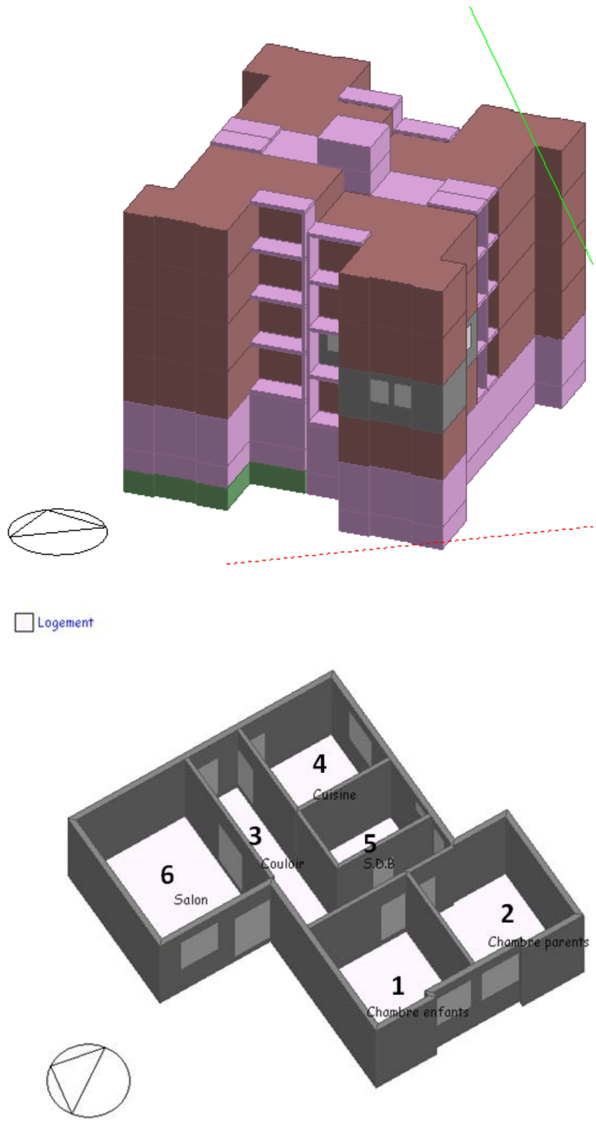

Fig. 12. 3D simulation model of the studied apartment and building (source: Author, 2015).

All cases have been simulated with three different ventilation rates in Air Change per Hour (ACH) assumed when the building is closed because of: firstly the difference of infiltration over time depending on changing winds speed and direction; secondly, the user behavior (opening/closing windows). These rates should roughly correspond to untight (2 ACH), rather tight (1 ACH) and very tight (0.5 ACH) windows.

In summer, windows are most of the time open, but during winter, they are open just for housecleaning, while windows are open during autumn and spring days. When the windows are open, a rate of 10 ACH is supposed (Rosenlund *et al.*, 2005; Šadauskiene, 2016). The energy use presented in results below depends on equipment's coefficient of performance (COP) (see Table 4).

Table 4. Ventilation rates in Air Change per Hour (ACH) (source: Author).

Volume	**Hours**	**Ventil-ation (ACH)**	**Comment**
Autumn, 1-31 October Spring, 1 April-31 May			
1-6	08-20 20-08	Open[a] Closed[b]	
Winter, 1er November – 31 March			
1-6	10-11	Open	Just for housecleaning
	11-10	Closed	Heated at 21 °C by a spot heating of natural gas (COP[c]=0.87)
Summer, 1er June – 30 September			
1-6	20-9	Open	Free cooling
	9-20	Closed	Air-conditioned at 25 °C No cooling is supplied, but it is arranged by autonomous electric air-conditioners (COP=3.06)

a: 'Open' means 10 ACH; b: 'Closed' means 0.5-1 and 2 ACH depending on case, see results; c: Coefficient of performance

Domestic Hot Water is ensured by an autonomous gas water heater having a COP of 0.85 to heat a daily water volume of 50l/day/per. Next, identifying materials used in the studied building elements, those are already presented in Table 1. As well as, the optimized building elements as shown in Table 5.

The hourly climate data of Tlemcen based on thermal reference year generated by the software Meteonorm (version 5.1.) was applied to the buildings parameters for the whole year and in some cases for typical days of July and January. In the passive case the apartment is considered as a multi-zone, but in the active one, zones are merged onto a single zone because there is one source of heating.

9. Results analysis

After the simulation and the confirmation of the data, the calculations of heating, cooling loads and CO_2 emissions, together with temperatures of apartment and volumes were then run by the DesignBuilder program to give the following results.

9.1. Active case results: energy efficiency and environmental impact

The yearly heating and cooling demand as well as CO_2 emissions for the baseline –the existing non-insulated apartment in the middle corner of the building with two exposed faces and single-glazing- is shown in Figure 13 for three different minimum ventilation rates. The untight actual case is positioned in 'class 7' of Tunisian label and in 'level D' of the BBC label which has bad energy performances.

9.1.1. Effect of ventilation reduction

The potential of heating and cooling energy saving by reducing ventilation is noticeable. The tightest apartment has an energy use of about 62% of the untight one and reaches the 'class 5' of the Tunisian thermal and energy regulation of new buildings (RTETBN) as minimal limits. The CO_2 emission reduction is about 22% in the tight apartment compared to the untight one, pushing the environment ranking from 'level F' to 'level E'.

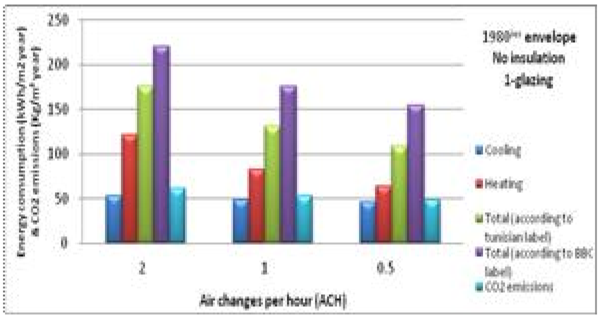

Fig. 13. Yearly heating, cooling and total demand together with CO_2 emissions per sq. m of a non-insulated apartment (middle corner of building) with simple glazing. This case represents the baseline, existing building (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

9.1.2. Insulation effect

Placing the insulation layers in the studied apartment's envelope, (see Figure 14) can save about 41% of heating and cooling energy in the untight apartment, about 64% in the medium and 57% in the tight one. Pushing the ranking to 'class 1' in Tunisian label and to 'level C' in BBC label, saving about 32% of energy in the untight apartment, 38% in the medium and 41% in the tight one. Also, reaching the 'level D' of environment etiquette in the tightest apartment that can save 43% of CO_2 emissions compared to the untight base case.

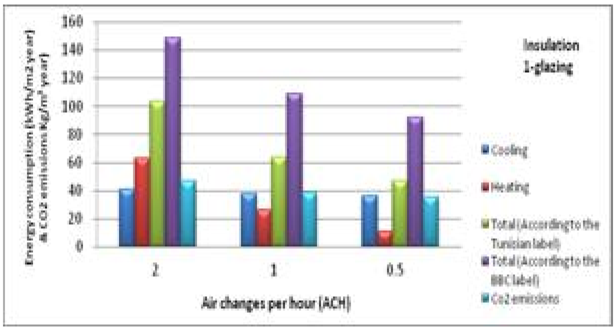

Fig. 14. Yearly heating, cooling and total demand together with CO_2 emissions per sq. m of an insulated middle corner apartment with single glazing (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

Table 5. Summary of the energy efficiency measures (source: Author).

Measure	Description	Area/Length (m²/ml)	Total U-value (W/m²C°)	Additional benefits	Investment costs (€)	Life cycle duration (year)
Weather strip	Strip of felt	9.11	-	Reduce the infiltration	6.21	10
Façade insulation	External-Glass Wool Pannel-3cm	106.78	0.770	Reduce the thermal bridge	6717.6	>25
Partition insulation	Internal-moderately rigid cellulose wool	27.36	0.745		321.13	25
Roof insulation	Inverted-EPS	89.85	0.593		622.13	>25
Window pane change	3/6/3		3.159	Reduce air infiltration	283.12	25
Windows sizex1.5	3/6/3 PVC	17.79	3.159		4314.58	25
Glazed veranda	3/6/3 PVC	3.2	3.159		776.26	25
Solar protection	Awning	Line: 1.5 way out: 0.8	-	-	1260.31	10

The effect of insulation is thus greater if ventilation is kept low. Combining reduced ventilation and moderate insulation can give as much as 73% heating and cooling energy saving.

9.1.3. Effect of double glazing

The effect of double glazing, compared to single one, for the insulated case is 42% of energy saving in the untight apartment and about 59% in the tight one. The combination of the two precedent parameters with the double glazing can save more than 74% of heating and cooling energy and more than 59% of total energy including domestic hot water and lighting energy (see Figure 15).

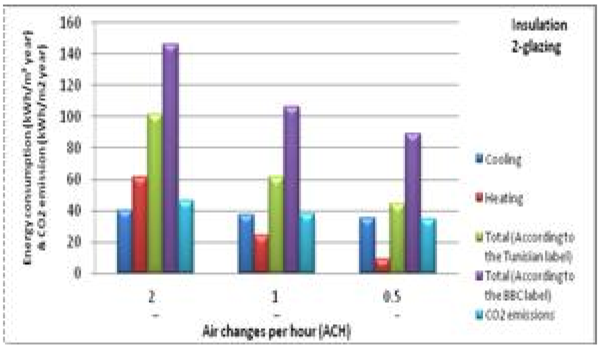

Fig. 15. Yearly heating, cooling and total demand together with CO_2 emissions per sq. m of an insulated middle corner apartment with double glazing (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

For the uninsulated apartment, the corresponding saving is only 2%. But it is about 39% in the tightest one compared to untight base case, to achieve the minimum limits of the RTETBN 2008. And the 'level C' of BBC label saving more than 31% of energy in the tight apartment compared to untight base case. Combination of double glazing with reduced ventilation have also a low effect on the environment label, staying only in 'Level E' and reducing about 23% of CO_2 emission compared to the untight base case (see Figure 16).

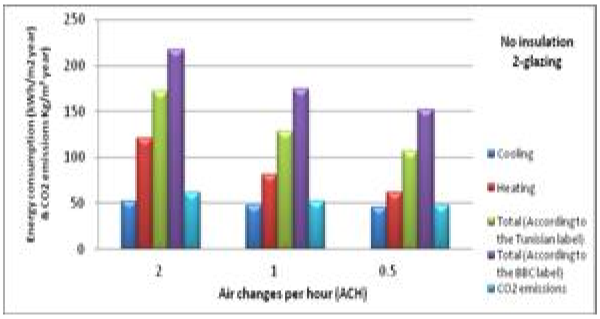

Fig. 16. Yearly heating, cooling and total demand together with CO_2 emissions per sq. m of a non insulated middle corner apartment with double glazing (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

9.1.4. Orientation effect

Actual case facades are oriented to the south-east and south-west, which can give an absolute gain of solar energy during winter. But, it can also cause a real overheating during summer.

It has been found, that orienting facades towards the north-east and north-west conducts to a supplementary use of 23% of energy for heating in the untight case, 30% in the medium and 35% in the tight one; and to an energy saving of 11% for cooling in the medium and tight cases.

By orienting facades towards the north-east and south-east, the results show a supplementary use of 13% of energy for heating in the untight case, 17% in the medium and 20% in the tight one; and an energy saving between 12-13% for cooling in the three cases.

And the results show that by orienting facades towards north-west and south-west, a usage of more than 10% of energy for heating in the untight apartment, 13% in the medium and 16% in the tight one are noted; and an energy saving about 16-17% for cooling in the three cases (see Figure 17). So, we can conclude that orienting the building towards the north, the east and the west is not efficient and that the original case oriented to south is the best orientation for energy saving.

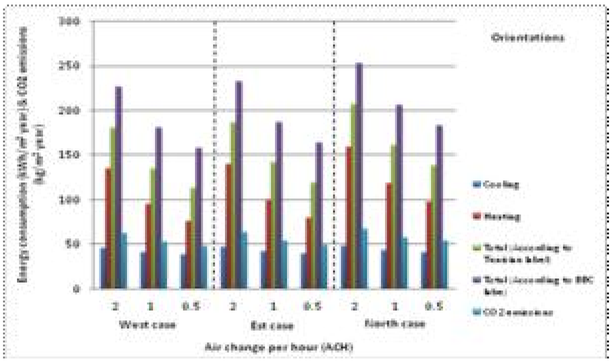

Fig. 17. Comparison of yearly heating, cooling and total demands together with the CO_2 emissions per sq. m of base case (non insulated, simple glazing in middle building), placed in the three other orientations (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

All cases above have displayed three cases of ventilation rates: high, medium and low. From these cases, it can be concluded that reducing the ventilation to 1/2-1/4 generally saves from 38% to 75% of energy.

9.1.5. Effect of another envelopes' inertia

If we compare the studied apartment envelope -constructed using heavy prefabrication- with another existing one using a reinforced concrete support structure and a hollow brick filling wall, we note that the positive influence of the materials inertia used in this later (using the red-hollow-brick in double walls of 10 and 15cm separated by 5cm of air gap in the outer wall, having a U-value=1.344W/m².K and the same red-hollow-brick of 15cm in the wall separating the apartment from the non-heated space, having a U-value= 2.381W/m².K and 16cm of concrete-hollow-blocks and 4cm of reinforced concrete in the roof and the ceiling having a U-value=0.439W/m²K) is also evident. This saves more than 34% of heating and cooling energy in the medium apartment and 50% in the tight one compared to the untight case having the same envelope.

But, comparing it with base case envelope, heating and cooling energy saving is about 31% in the untight, 39% in the medium and about 45% in the tight apartment. It also saves about 55-66% compared to the untight base case. Whereas, CO_2 emissions level, in the three minimum ventilation rates, is always in 'level E', but it saves about 22-23% of CO_2 emissions in medium and tight apartments compared to untight one and 20-40% compared to untight base case (see Figure 18).

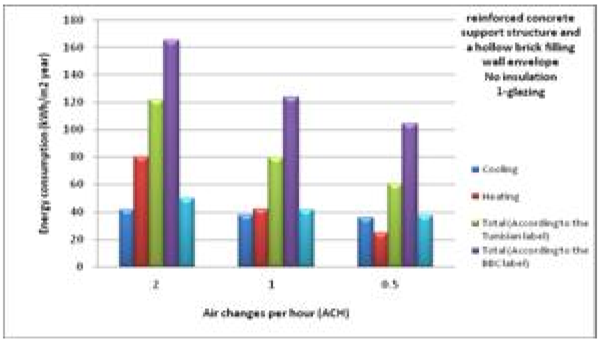

Fig. 18. Yearly heating, cooling and total demand together with CO_2 emissions per sq. m of a non insulated apartment with a reinforced concrete support structure and a hollow brick filling wall envelope (middle corner of building), with simple glazing (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

9.1.6. Effect of apartment location

By placing the baseline apartment in the top corner position we note that the untight apartment has a very bad level of energy performance: 'class 8' of the Tunisian label and 'level E' of BBC label. The tight non insulated apartment at top corner has a supplementary heating and cooling energy use of about 10% of the tightest base case in middle floor/corner, recorded mainly by the heating energy that requires 15% more than the middle floor/corner apartment (see Figure 19). While, an insulated and double glazed apartment at the corner of the top floor consumes for heating and cooling about 55kWh/m² year, having a supplementary need of energy of 19% more than a corresponding middle apartment. So, the top corner or top floor apartments require additional insulation because of the calorific losses of roof.

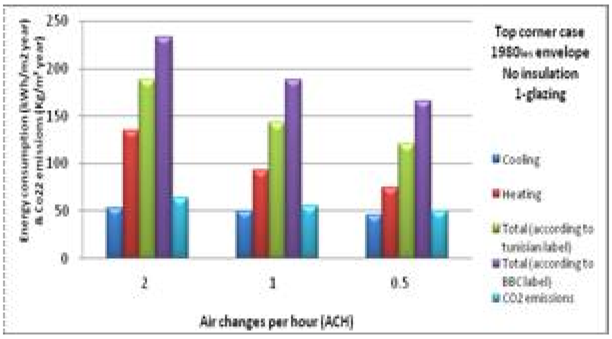

Fig. 19. Yearly heating, cooling and total demand together with CO_2 emissions per sq. m of a non insulated top corner apartment with simple glazing (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

9.1.7. Effect of increasing the sizes of south-facing windows

Another way of further reducing the heating need is to increase solar gains. In Figure 20, the size of the south facing windows of the insulated double glazed apartment is increased to one and a half. Only the low-ventilation apartment is calculated. Its heating need is substantially reduced compared to the baseline case saving about 90% of heating energy namely about 10 times a corresponding tightest base case and more than 2 times less than the passivhaus requirements. But, it saves just 14% of cooling energy compared to the tight baseline case. While, this saves more than 74% of heating and cooling energy compared to the untight base case. And 58% compared to the tight one. And about 59% of total energy including domestic hot water and lighting energy compared with the untight base case and 41% compared to the thight one. In addition, it saves 43% of CO_2 emissions compared to the untight base case and 27% compared to the tightest one.

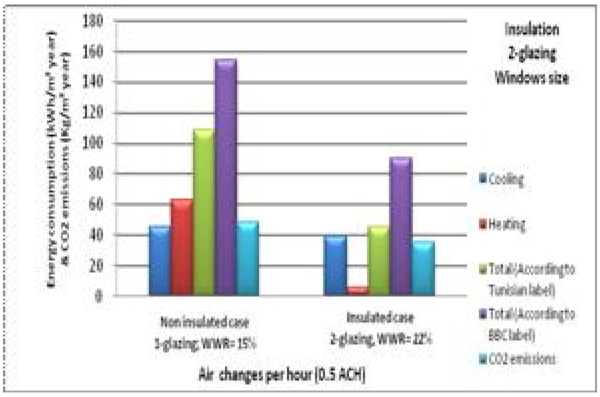

Fig. 20. Comparison of yearly heating, cooling and total demands together with the CO_2 emissions per sq. m of tight base case (non insulated, simple glazing in middle building), with an insulated, double glazed apartment with increasing of south facing windows size to 1 and ½ (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

9.1.8. Effect of glazed veranda

One of the common actions of retrofitting apartments in Algeria is placing greenhouses in the kitchen verandas to increase the kitchen area and to protect the veranda from weather. But is it beneficial for the interior climate? The Figure 21 shows that heating energy saving is estimated more than 85% in an insulated apartment with double glazing and glazed veranda compared to the tight base case and the energy saving of cooling is more than 15%. This same case saves 86% of heating energy and about 20% of cooling energy compared to a non insulated apartment with simple glazing and a glazed veranda. While, this later has a supplementary need of cooling up to 6% than the tight base case.

To contend the overheating phenomenon during summer, two dispositions, in addition of increasing ventilation, can be taken: the glazed panels can be totally folded up, in order to recreate a simple balcony; besides, these greenhouses must carry shading devices to protect them from incident solar radiation during summer. So, placing greenhouses using single glazing in the kitchen verandas of a non insulated apartment is not efficient. However, it consumes more energy.

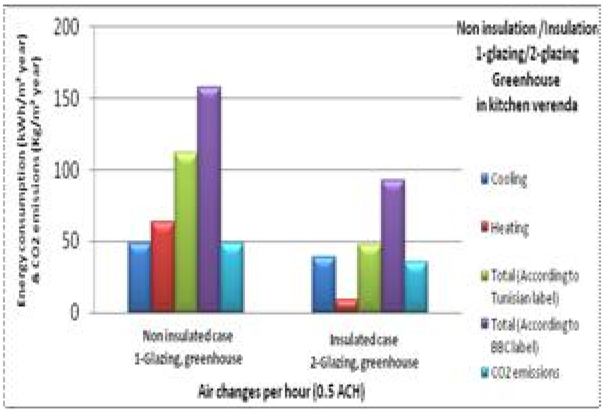

Fig. 21. Comparison of yearly heating, cooling and total demands together with CO_2 emissions per sq. m of the tight base case with greenhouse and an insulated middle apartment, with double glazing and greenhouse in kitchen balcony (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

9.1.9. Effect of shading devices

To avoid overheating in summer, many suggestions of shading device, with different dimensions, have been simulated (louvers, overhangs and fins or their combination). The most efficient case is the one to which 65cm moveable overhangs are added, in addition of shading that is given from the depth of windows in an insulated middle corner apartment with double-glazing and greenhouse. Assuming that the ventilation is kept at a minimum, cooling load decreases to reach more than 36KWh/m² yearly. While, heating load reach less than 10KWh/m² yearly, instead of more than 63KWh/m² yearly to heat a non-insulated tight middle corner apartment with single glazing. Total energy saving is estimated to 57% compared to tight base case and to more than 73% compared to the untight one. While, it saves 27% of CO_2 emissions compared to tight base case and about 39% compared to untight one (See Figure 22).

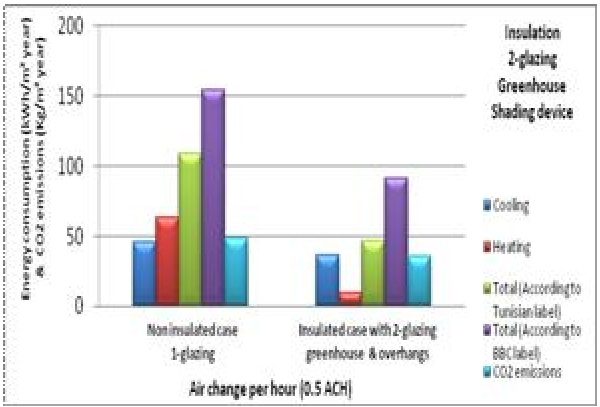

Fig. 22. Comparison of yearly heating, cooling and total demands together with CO_2 emissions per sq. m of tightest base case and an insulated middle apartment, with double glazing and shading device combined to glazed veranda (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

9.2. Economical Rationality analysis results

After analyzing carefully EE and EI criteria, we have established an economic impact study according to the method explained in (Missoum *et al.*, 2014). It has been found that only the actions related to: changing the windows panes, placing a window in veranda and solar protections are cost-effective, to record payback times of 7, 15 and 22 years respectively. In addition to the caulking of windows and doors that has low cost. While, investment cost of: insulation and changing windows are very high. The key arguments are the actual prices of insulation materials in the Algerian market (see Table 5), and the energy price! It is the less expensive in Africa, even the undeveloped countries pay the real price, because, it is conventionalized by the Algerian state. It is fixed basing on socio-economic criteria (with about 7000€/household as income level). Subventions are indirect through a reduction applied on benefits of production societies under state control (SONELGAZ). Energy prices in Algeria are blocked since the Decision D/06-05/CD of 30 May 2005 with 0.278DZD/kWh=0.0024€/kWh for natural gas and 4.179DZD/kWh=0.0356€/kWh for electricity.

9.3. The passive case results and analysis: Thermal comfort

9.3.1. Before rehabilitation

Passive results of actual case in Figures 23, 24 and 25, when no energy at all was used for heating and cooling, show that operative temperature in winter vary between 10.94°C and 13.33°C. This temperature is lower than comfort zone which vary between 21°C and 25°C (considered in the DTR.C3-2). Therefore, comfort is not yet insured. Thus, in summer, thermal comfort is also not insured, because operative temperatures vary between 28.03°C and 33.01°C.

9.3.2. After rehabilitation

After improving apartment envelope elements as it has been explained previously in Table 5, the results show that losses after rehabilitation are lower than the actual case ones; temperature is improved in winter as in summer. Improvement of internal operative temperature in winter has reached 17.65°C and 18.52°C and between 28.26°C and 31.18°C in summer. Very helpful heat and cooling gains which will improve thermal comfort and decrease energy consumption and CO_2 release, but which are not sufficient to achieve thermal comfort zone. Nevertheless, an important insulation can cause overheating in summer, though the ventilation must be rightly studied.

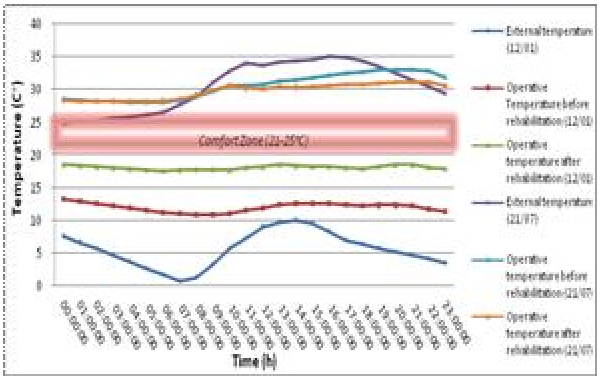

Fig. 23. Operative temperature in the apartment before and after the thermal rehabilitation in winter (12/01) and in summer (21/07) (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

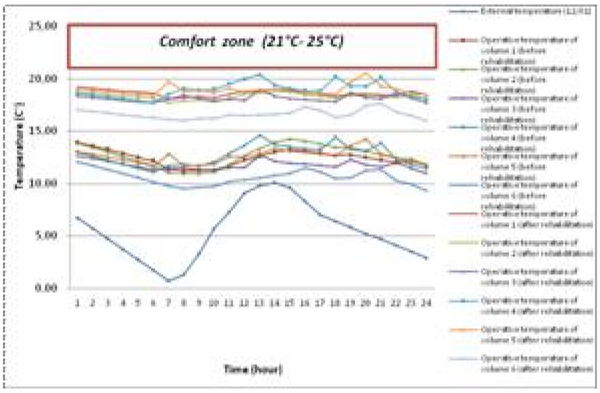

Fig. 24. Operative temperature in volumes before and after thermal rehabilitation in 12/01 (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

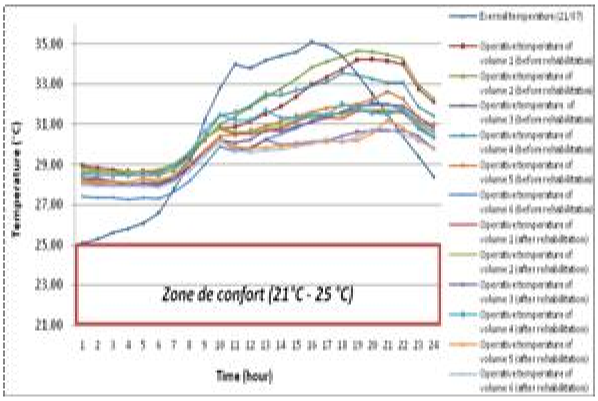

Fig. 25. Operative temperature of volumes before and after thermal rehabilitation in 21/07 (source: Generated by Excel Template by the author according to simulation results using DesignBuilder© Software, 2016).

10. Conclusion

In this article, a sustainable solution for the optimization of EEP in the existing housing in Tlemcen is investigated. To achieve this multi-objective approach as in the study of Gossard *et al.* (2013), a multi-criteria assessment of passive EEM has been performed in order to retrofit a multi-storey apartment envelope. The results, confirmed by the study's findings of Mikučionienė *et al.* (2014), Ouahab (2015), Liu *et al.* (2015), Lawania and Biswas (2016) and Ortiz *et al.* (2016), have shown that energy saving is the key of a contribution effectively measurable to sustainability and climate protection.

These results have also confirmed the necessity of thermal rehabilitation translated by the rapidly decrease of the annual energy requirements with the first few centimeters of insulation. That conducts to the obligation of applying the thermal regulation. Together with, the development of this latter in order to elaborate specific norms to different climatic zones and to establish Algerian proper sustainable design guideline appropriate to the socio-economic context, which is consistent with the goal of the study of Huang *et al.* (2012). In this topic, the need of a consolidated Algerian energy efficiency politics combining, in the same time, tariffs reform and consumption reduction as recommended by Ouyang *et al.* (2011), in order to limit the increase in the invoice for the population, especially for the most destitute is a necessity. The energy pricing affects the profitability of energy improvements. And a tariff blocking, as in the Algerian context, can limit artificially the investment alternatives in these improvements.

Table 6. Matrix of different energy-saving actions. Tentative savings for typical multi-storey dwellings (middle of building) in the Tlemcen climate, based on the computer simulation study (source: Author).

Action	Typical heating and cooling saving	Tunisian Energy Class	Typical total saving (including ESC+lighting energy)	BBC Energy Level	Typical CO_2 Emissions saving	BBC Environment Level	Cost level				Suitable for		
												Retrofit by	
							No	Low	Medium	High	New building	User/ Tenant	Owner/ Manager
Ventilation reduction (keeping closed)[a]	37-75%	Class 1	30-59%	Level B	15-44%	Level D	X				X	X	
Weather stripping of windows[a]	37-75%	Class 1	30-59%	Level B	15-44%	Level D		X			X	X	X
Larger south windows (sizex1,5 , 2-glass)[a]*	74%	Class 1	59%	Level B	43%	Level D				X	X		
Moveable shading device combined to glazed veranda (2-glass)[a]*	73%	Class 1	58%	Level C	39%	Level D			X		X		X
Envelope insulation[a]	64-73%	Class 4-1	51-58%	Level C	24-43%	Level E-D				X	X		X
Double-glazing[a]	39%	Class 4	31%	Level C	25-44%	Level E				X	X		X
Glazed veranda (2-glass)[a]*	56%	Class 1	40%	Level C	38%	Level D				X	X		X
Double-glazing[b]	26-39%	Class 7-5	21-31%	Level D-C	23%	Level F-E			X		X		X

a. Moderate insulation; b. No-insulation; *. For low ventilation rates.

Therefore, we try to assign an order of priority of actions to lead in short, medium and long term, using a multitude of more or less advanced tools, according to the potentials of energy saving and those of CO_2 emissions reduction, to improve EEP in existing dwellings together with conception of new ones, given by the limited parametric study used by Belpoliti and Bizzarri (2015), indicated in Table 6.

Appendix A

Table A.1. Benchmarking of international thermal regulations and existing energy saving labels and certificates (source: Author according to (ANME, 2010; Charlot-Valdieu and Outrequin, 2011; Bertucci and Ogier, 2010)).

kWh/ m².year	Labels and referential	Objectives of consumption	Certification/promotion Criteria taken into account	Concerned equipments
80-250	RT[a] 2005 (Decisions : May 2006 for the new, May 2007 for the renovation)	80 to 250kWh/(m². y) according to the climatic zones.	Thermal insulation, introduction of the bioclimatic and the renewable energy.	Heating/cooling System Production of sanitary hot water. + auxiliaries and lighting for Effinergie Expressed as primary energy.
231	PH and E[b] certification	They are reserved to owners of multi-story buildings and can covering the co-ownership field. To achieve this certification, energy consumption must be less than 231kWh/(m².y).	Qualitel- Cerqual Patrimoine[c]	
72-225	HPE[d] /HPE EnR[e] (Decision: 2007 for the new), HPE renovation (Decision : September 2009 for the renovation: for buildings built after 1948)	-RT2005 -10% For the THPE EnR, 50% of the heating energy must be derived from the biomass or from a heat network using more of 60% of renewable energy. HPE renovation (high energy performance renovation): maximum consummation of 150kWh/(m². y), according to the altitude and the climatic zones.		
56-200	THPE[f] / THPE EnR (Decision : May2007)	RT 2005 -20% (-30% for the THPE EnR)		
80-150	PC ; PC and E[g]	Performance levels required are: - 1 Star: minimal techniques related to insulation (roof or façade, double glazing ;	Qualitel- Cerqual Patrimoine These new certifications concern six topics: Energy performance;	

Table A.1. Benchmarking of international thermal regulations and existing energy saving labels and certificates (source: Author according to (ANME, 2010; Charlot-Valdieu and Outrequin, 2011; Bertucci and Ogier, 2010)).

kWh/ m².year	Labels and referential	Objectives of consumption	Certification/promotion Criteria taken into account	Concerned equipments
		- 2 Stars realization of a series of works with a minimal performance; - 3 Stars low than 150kWh/(m². y) of primary energy (climatic zones, altitude); - 4 Stars low than 80kWh/(m². y) of primary energy	accessibility and usage quality (senior citizen-handicapped persons); health (sanitary quality) and security (fire); close and cover (material choice, facade, cover and body protection); equipment and the comfort of common parts (elevator, domestic wastes areas, lighting); acoustic.	
105-125	RTEBNT[h] 2008	The regulation must target the class 5: 105-125kWh/(m² y) in 2008 according to the climatic zones.	Thermal insulation, introduction of the bioclimatic, economical lighting and the renewable energy.	Heating/cooling System Expressed as primary energy.
85-95	RTEBNT 2010	The regulation must targets the class 3: 85-95kWh/(m². y) in 2010 according to the climatic zones RTEBNT 2008 -25%		
40-125	BBC[i](Decision: May 2007 for the new), BBC renovation (Decision: September 2009 for the renovation : for buildings built after 1948)	- In the dwellings, the energy consumption vary from 40 to 70kWh/(m². y), according to the altitude and the climatic zones. -BBC renovation (low energy consumption building renovation): maximum consummation of 80kWh/(m². y), according to the altitude and the climatic zones. For the tertiary, the global energy consumption = RT2005 -50%.	Certivéa- Cerqual – Céquami[j]- Promotélec[k]. Referential positioned by Effinergie®[l]. Criteria: thermal insulation, renewable energy, Bioclimatic, air imperviousness, ventilation, global quality of the building	Heating/cooling System Production of sanitary hot water. + auxiliaries and lighting for Effinergie Expressed as primary energy.
<75	RTEBNT 2012	The regulation must targets the class 1:<75kWh/(m². y) in 2012 according to the climatic zones RTEBNT 2008 -40%	Thermal insulation, introduction of the bioclimatic, economical lighting and the renewable energy.	Heating/cooling System Expressed as primary energy.

Table A.1. Benchmarking of international thermal regulations and existing energy saving labels and certificates (source: Author according to (ANME, 2010; Charlot-Valdieu and Outrequin, 2011; Bertucci and Ogier, 2010)).

kWh/ m^2.year	Labels and referential	Objectives of consumption	Certification/promotion Criteria taken into account	Concerned equipments
40-65	RT 2012 (Decisions : April 2013 for the new, January 2013 for the renovation)	40 to 65kWh/(m^2. y) according to the climatic zones	Thermal insulation, introduction of the bioclimatic and the renewable energy.	Heating/cooling System Production of sanitary hot water. + auxiliaries and lighting for Effinergie Expressed as primary energy.
40-80	Minergie®[m] (Switzerland 1996)	Primary energy for the dwellings: - New: between 40 to 45kWh/ (m^2 y); - Renovation : 60kWh/(m^2.y).	Prioriterre (Haute-Savoie) Criteria: air imperviousness (save Minergie®), soft aeration, renewable energy, limitation of thermal bridges. + equipments and economical lighting for Minergie P® Minergie Eco: day lighting, muffler protection, air quality, construction quality.	Heating/cooling system Production of sanitary hot water Electricity for ventilation The calculation include the production of photovoltaic lighting
30	Minergie P® (plus) (2003)	Primary energy : new : 30kWh/(m^2. y).		
30	Minergie ECO® (2006)	Destination to the administrative and locative buildings, the schools. Retake Minergie® et Minergie P® with healthy and ecological materials.		
15	Passivhaus®[n] (Germany 1990) Maison passive (France 2007)	Gross heating requirement: maximum of 15kWh/(m^2. y) (whatever been the altitude and the climatic zone). Total primary energy, equipments included: maximum of 120kWh/(m^2. y)(*).	La Maison passive France (LaMP®). Criteria: air imperviousness, insulation, suppression of thermal bridges, orientation to sun, ventilation, high performance household appliances.	Heating/cooling system Ventilation (*) + Production of sanitary hot water All equipment in the house

a. French thermal regulation; **b.** Heritage Houzing « Patrimoine Habitat », Heritage Houzing and environment « Patrimoine Habitat et Environnement »; **c.** Is a filial of Qualitel society ; **d.** High energy performance; **e.** Renewable energy; **f.** Very high energy performance; **g.** co-ownership Heritage «Patrimoine copropriété» and Heritage co-ownership environment «Patrimoine copropriété environnemen» ; **h.** Tunisian thermal and energy regulation of new buildings; **i.** Low consumption building: Bâtiment basse consommation: the label BBC, the environment label: is a French label; **j.** Quality Certification on individual houses, affiliate of CSTB and Qualitel society, created in 1999, is commissioned by Afnor Certification, owner of mark "NF Maison individuelle » and « démarche HQE® » for existing buildings; **k.** Promotelec is a society aiming to promote the electricity usage in the residential building and small tertiary; **l.** is a society aiming to "promote, in a dynamic way, the low energy consumption buildings in new and in renovation and to develop in France an energy performance referential of new or existent buildings. BBC label is created by this society in 2007; **m.** The Prioriterre society delivered the Minergie label stem from the Swiss label éponyme; **n.** Is a German norm which has been initiated in 1989 by Wolfgang Feist (Passivhaus Institute director), it is the best criterion of performance all over the world for the economy of energy. Its limits of energy consumption for heating and cooling are 80% less than for the Low Energy House and about 6 times less than that is planned by the French thermal regulation (RT2000) and 4 times less than the German regulative value.

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