Received 16 September 2018
Revised 1 March 2019
25 May 2019
19 July 2019
Accepted 24 July 2019

Assessment of energy performance using bottom-up method

Exemplified by multi-storey buildings in Tlemcen (Algeria)

Khadidja El-Bahdja Djebbar
Département d'Architecture, Faculté de Technologie, Université Abou Baker Belkaid, Tlemcen, Algeria and Laboratoire Matériaux Sol et Thermique, Département de Génie Civil, Universite des Sciences et de la Technologie d'Oran Mohamed Boudiaf, Oran, Algeria
Souria Salem
Département d'Architecture, Faculté D'Architecture et de Génie Civil, Université des Sciences et de la Technologie d'Oran Mohamed Boudiaf, Oran, Algeria, and
Abderrahmane Mokhtari
Laboratoire Matériaux, Sol et Thermique, Département de Génie Civil, Faculté D'Architecture et de Génie Civil, Université des Sciences et de la Technologie d'Oran Mohamed Boudiaf, Oran, Algeria

Abstract

Purpose – The purpose of this paper is to analyze energy performance of the multi-storey buildings built in the city of Tlemcen between 1872 and 2016.

Design/methodology/approach – A diagnosis based on a bottom-up methodology, using statistical techniques and engineering, has been developed and applied. To do this, demand condition analysis was conducted using a data collection survey on a sample of 100 case studies. Physical characteristics of the buildings have been determined through the archetype by period. This serves to define the strengths and weaknesses of buildings as energy consumers.

Findings – The obtained results showed that dwellings built between 1872 and 1920 offer better energy performance with a consumption index close to 130kWh/m^2/year and this compared to the five periods considered. For dwellings built between 1974 and 1989, energy consumption is higher with an index approaching 300kWh/m^2/year, thus qualifying the buildings of this period as energy intensive.

Originality/value – A database is established to collect physical information on the existing housing stock and thus allow their classification *vis-à-vis* of the energy label. This study is part of a research project aimed at evaluating and determining optimal measures for energy rehabilitation of multi-family buildings in Tlemcen. Thermal rehabilitation solutions are proposed using thermal simulations, in the following studies, to improve thermal performance of existing buildings. This study constitutes the first step of a roadmap applicable to other cities constituting climatic zones in Algeria. This helps to enrich the Algerian thermal regulation in thermal rehabilitation of existing residential buildings and conception of new ones, in urban areas with a similar climate.

Keywords Housing, Archetype, Algeria, Architectural typology, Bottom-up approach, Energy performance

Paper type Research paper

1. Introduction

Alone responsible for 43 percent of the final energy consumption (ME, 2017) and an equal and important share for the delivery of greenhouse gas emissions in Algeria, the residential sector is one of the causes of the problem, but also one of the main solutions. Improving the energy performance of buildings, particularly for residential buildings,

International Journal of Building Pathology and Adaptation
Vol. 38 No. 1, 2020
pp. 192-216

2398-4708
DOI 10.1108/IJBPA-11-2017-0056

is one of the actions that should be pursued in order to achieve the Kyoto and Copenhagen targets.

Based on a typology provided by the National Office of Statistics of Algeria, Ouahab (2015) considers that the energy consumption of buildings varies considerably according to the type of housing. The disaggregated projection of the dynamics of the park on a departmental scale shows a numerical increase in the number of units in multi-storey buildings. Their number would rise from 1.01m in 2008 to nearly 5.45m in 2050. Statistics predict that 82 percent of the Algerian population will be concentrated in the cities by 2020. As a result, the existing residential sector has a very high potential for energy savings. It is the one that faces more obstacles too. Analysis of energy consumption shows that the residential sector consumes 40 percent of total national electricity consumption. Thus, it is the first sector that consumes large amounts of electricity at the national level and 60 percent of the final consumption of fuel. According to Agency for the Promotion and Rationalization of the Use of Energy report, in the sectoral carbon dioxide emission balance, the building is classified second (30 percent) after transport (50 percent) and before industry (12 percent), that to say an emission of 25.3m teq CO_2 (tons CO_2 equivalents) (Denker *et al.*, 2014).

Popular pressure on housing is pushing for quantitative and non-qualitative achievements: total lack of energy efficiency. There is evidence of the inefficiency of the control and sanctions mechanism and thus the non-application of thermal regulations in new buildings, which was to take effect as early as 2005 (Sénit, 2008). Algeria is energy-rich, it must not squander this wealth through non-isolated housing and therefore high energy loss.

Algeria is not an exception. Thibault and El Andaloussi (2011) estimate an energy saving potential in Southern and Eastern Mediterranean Countries at more than 320m TOE (ton of oil equivalent) cumulated final energy gains over the period 2010–2030 in the building sector. The largest reductions, according to usage, come from heating and air conditioning for about 60 percent. According to this scenario, the annual reduction in CO_2 emissions would be around 179m teq CO_2 in these countries. So, the promotion of thermal rehabilitation of buildings is necessary by ensuring that the available measures are profitable in the long term. In addition, it significantly improves the comfort of users.

This led the Ministry of Housing and Urban Planning to publish Regulatory Technical Documents (DTR) in 1997, which aim to reduce building's heat losses and give rules of Calculation of Summer Calorific Gain. These documents were updated in 2014.

As a result, detailed studies are needed to examine all the factors that influence the energy consumption of buildings: climate, building characteristics, user characteristics and lifestyles, performance of energy systems and appliances and their use. Such consideration is developed regarding the multi-storey residential buildings stock in the city of Tlemcen, taken as a case study, and presented in this document.

2. State of the art

In recent years, several studies have been carried out throughout the world with the objective of characterizing the housing stock and evaluating its potential for energy savings. According to Swan and Ugursal (2009), the main techniques used to model residential energy uses can be grouped up into two main categories: top-down and bottom-up. Top-down models underwent a major development during the energy crisis of the late 1970s (Ortiz *et al.*, 2016).

The major aim of such research effort was to understand better consumer behavior with changing supply and pricing. Such models analyze residential sector as a whole and their objective was to determine and to analyze trends of the sector. The strength of "top-down" models is that they do not need very detailed input data to work. 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. While, the bottom-up approach goes beyond the limits of the top-down one, accounting in detail for individual houses and energy end uses. After that, the results of the model can be extrapolated to represent a region or a nation, according to the level of detail of the inputs. It 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). Statistical techniques are based primarily on historical data to identify the relationship between final energy demand and production. Many researchers apply this method to assess energy use in the residential sector. This technique relies on the information provided by customers' energy billing to build its databases (Ouahab, 2015). Researchers have developed several methods for estimating energy consumption. We can quote: the regression analysis used by Famuyibo *et al.* (2012): is used to determine the coefficients corresponding to each input parameter of the data in the model; the demand condition analysis technique: assesses the final energy consumption of different appliances in a dwelling (Swan and Ugursal, 2009) Op. cit. It is this technique which seems to us to be useful for the creation of the database in this study. The "Neural Network" (NN) technique, used by Gossard *et al.* (2013), is a computational model whose design is schematically inspired by the functioning of biological neurons. It is based on mathematical models of NNs.

Wilson and Swisher (1993) point out that the combination of building physics and empirical data from housing surveys, as well as assumptions about building operations, provide modelers with tools to estimate energy use in past, present and future dwellings. This helps to identify technological measures using various scenarios and bottom-up models. It provides decision makers with estimation of the effectiveness of energy policies.

On the other hand, Ouahab (2015) highlights the main limitation of the engineering method, which is the lack of transparency in quantifying the impact of occupant behavioral factors on energy consumption. In addition, this type of approach requires a certain amount of detailed and precise data, demographic or technological, concerning the park, which are sometimes difficult to collect (because not accessible to the public). This constitutes a real obstacle to the realization of this method of modeling.

The construction of typologies can be a useful tool to facilitate the assessment of the energy performance of a building and can be used in the analysis of policy strategies for planning the future improvement of the energy performance of residential buildings. The archetype or building typology is an engineering bottom-up approach and it is defined as a sample of building that is representative of actual buildings. As the building stock of a country consists of buildings with different characteristics, several building typologies are required in order to derive the thermal characteristics of the building stock (Ortiz *et al.*, 2015, 2016). Parekh (2005) proposes three basic criteria of archetypes:

(1) geometric configurations: these configurations include the plan layout of the building, volume and orientation;

(2) thermal characteristics: they include building envelope data (Ubât), heating and hot water systems, water tightness and ventilation systems; and

(3) operating parameters: they relate to basic consumption loads (lighting, appliances) and indoor temperature data.

In the last decades, several studies have applied this method to estimate the energy consumption of an urban, regional or national building stock.

The TABULA project (TABULA Project Team *et al.*, 2012) is one of the first initiatives to create a European database to collect information on the existing building stock.

Based on the common DATAMINE data structure and the experiences of typological classification the TABULA project was launched in 2009. The idea was to make an agreed systematic approach to classify building stocks according to their energy-related properties.

Based on the work developed in the TABULA project, Dascalaki *et al.* (2011) used Greece's residential building typologies as a showcase to demonstrate energy performance and the potential for energy savings from the point of view of typical and advanced energy saving measures on the thermal envelope and the heat supply system.

Mata *et al.* (2014) describes a systematic description methodology of the housing stock in European countries (France, Germany, Spain and the UK) based on the archetypes buildings, in order to estimate the energy consumption of the building sector using the energy of the model, Carbon and Cost Evaluation of Building Inventories (Mata *et al.*, 2013).

Ivancic *et al.* (2014) have developed different tools, (geographic information system (GIS) and an energy and environmental balance simulator) to carry out the analysis of the energy balance, the evaluation of future scenarios and the optimization of the cost benefit of the city of Barcelona.

Garrido-Soriano (2010) and Garrido-Soriano *et al.* (2012) extended the work done by Ivancic *et al.* (2014) and make a detailed characterization of the residential housing stock of Catalonia.

The InnoCons Project (2012) analyzed the typology of the most representative buildings in Catalonia, pre-defined in Garrido-Soriano *et al.* (2012). In this case, the objective was to evaluate more deeply the renovation options for this type of building.

Manyes *et al.* (2013) applied a similar method to develop a building characterization in the neighborhood of Santa Coloma de Gramenet (Barcelona), with the difference that the scope of the study was a building level block rather than a regional level.

Hrabovszky-Horváth *et al.* (2013) presented a bottom-up methodology based on a generalized building typology of the residential building stock in order to estimate the mitigation potential and vulnerability of the residential sector in Hungary.

Belpoliti and Bizzarri (2015) used the qualitative method. A simplified parametric calculation protocol was created to perform a preliminary audit and a simulation of energy renovation of the entire social housing stock in the Emilia-Romagna region (Italy) in terms of their envelopes and their heating system features.

In the "typology" branch of EPISCOPE project (EPISCOPE Project Team *et al.*, 2016), supported by the Intelligent Energy Europe Programme, the TABULA project was continued by updating building typologies and extending the underlying concept to further countries. In that framework also new or updated statistical data of the national residential building stocks was collected.

Based on the residential building typologies developed within the TABULA/EPISCOPE, Csoknyai *et al.* (2016) presented the analysis of heterogeneous data sources and collecting and comparing the information of the housing stock in Eastern-European countries (Bulgaria, Serbia, Hungary and the Czech Republic). This was under a common comparison framework of building typology data between countries, and the contribution in the harmonization of the building typology approach.

In the light of this bibliographic analysis, it appears that the use of the bottom-up model has several key advantages, which make it the most appropriate tool. Indeed, this paper focuses on this method to have an overview of the housing stock and its energy consumption. However, we lift an epistemic vacuum and lack local-depth specialized studies in this regard, and the lack of a holistic approach to a sustainable evaluation of the thermal and energy performance of residential buildings appropriate to the Algerian and Maghreb context. The effectuation of a diagnosis of the energy and thermal performance of multi-storey residential buildings, built in Tlemcen during the various periods of urbanization of this city, is the key action in the definition of a strategic method for the control of energy in residential buildings. In addition, the present study concerns the existing cluster of construction, and more specifically, it concentrates only on the buildings built during the French colonial period and those of post-independence.

3. Benchmarking of international thermal regulations and energy saving labels and certificates

The search for an ecological alternative in the building sector is part of international thinking. However, the complexity of energy regulation, the low level of performance required by it and the lack of control of compliance with regulations and building performance have led to the creation of certifications and labels (as HQE, LEED, BREEAM, etc.) (see Table I).

Given the energy challenges facing the buildings sector in developing countries, especially in the southern Mediterranean countries, most of them have adopted regulatory or normative measures for energy efficiency in buildings. However, in reality, the level of operationality of these measures differs significantly from one country to another.

The two countries where thermal regulation is relatively well applied are Turkey and Tunisia. Indeed, in these two countries, regulations have been developed according to a global process based on wide-ranging consultation with all stakeholders and associated with programs to support and reinforce the capacities of designers, operators and suppliers of insulation materials. In general, feedback from these countries shows the importance of the regulatory development process quality, as a key factor in its effective applicability. According to Grundström *et al.* (2003) the Algerian regulations are largely inspired by French regulations. On the other hand, the calculation methods used are simpler. They allow, at least within certain limits, computerized calculation of heating requirements. Comparing Algerian regulation with those of neighboring countries (Tunisia, Morocco, etc.), we noticed that it needs to be more in depth. The two Tunisian and Moroccan thermal regulations provide designers with information (heating need according to the climatic zone, minimum required consumption limits, energy label, etc.) that is stricter and clearer for each climate zone. Although, Algeria was among the first countries to have developed its regulatory framework and participated in the development of the Maghreb Building Thermal and Energy Regulation, it must close the gap with other countries that have implemented thermal regulations for mandatory buildings (Djebbar *et al.*, 2018).

4. Objectives of the study and methodologies

The originality of this study is to perform a preliminary analysis of energy performance of the multi-family housing in the town of Tlemcen, using bottom-up methodology through the statistical and engineering techniques. As mentioned in Belpoliti and Bizzarri (2015), to pursue a bottom-up approach, few case studies need to be selected and deeply analyzed. These authors chose 70 cases out of 58,395 dwelling units for the same purpose (i.e. 0.12 percent of the park). So, we have increased the representation of typologies to improve the characterization of the building in this city, to help technicians in the priorities of intervention attempts. Therefore, 100 units were selected from the multi-family housing stock (with 61,685 dwelling units, i.e. 0.16 percent) for their differences in construction date, size, shape, technology, heating system and number of dwellings in the park.

To perform this diagnosis correctly, this paper develops an appropriate methodology (shown in Figure 1). The work was carried out in three phases:

(1) Step 1: a data collection phase based on previous studies on the city of Tlemcen. The dating of buildings in Tlemcen was carried out as key information. Note that this

kWh/m^2. year	Labels and referential	Objectives of consumption	Certification/promotion criteria taken into account	Concerned equipment
80–250	RT[a] 2005 (decisions: May 2006 for the new, May 2007 for the renovation)	80 to 250kWh/(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
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/(m^2.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/(m^2. y), according to the altitude and the climatic zones		
56–200	THPE[f]/THPE EnR (decision: May 2007)	RT2005 −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 2 Stars realization of a series of works with a minimal performance 3 Stars low than 150kWh/(m^2. y) of primary energy (climatic zones, altitude) 4 Stars low than 80kWh/(m^2. y) of primary energy	Qualitel – Cerqual Patrimoine These new certifications concern six topics: energy performance; 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/(m^2 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

(*continued*)

Table I.
Benchmarking of international thermal regulations and existing energy saving labels and certificates

Table I.

kWh/m^2. year	Labels and referential	Objectives of consumption	Certification/promotion criteria taken into account	Concerned equipment
85–95	RTEBNT 2010	The regulation must targets the Class 3: 85–95kWh/(m^2. 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/(m^2. y), according to the altitude and the climatic zones BBC renovation (low energy consumption building renovation): maximum consummation of 80kWh/(m^2. 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/(m^2. 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
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 + equipment and economical lighting for Minergie P®	Heating/cooling system Production of sanitary hot water Electricity for ventilation

(*continued*)

kWh/m^2. year	Labels and referential	Objectives of consumption	Certification/promotion criteria taken into account	Concerned equipment
30 30	Minergie P® (plus) (2003) Minergie ECO® (2006)	Primary energy: new: 30kWh/(m^2. y) Destination to the administrative and locative buildings, the schools Retake Minergie® et Minergie P® with healthy and ecological materials	Minergie Eco: day lighting, muffler protection, air quality, construction quality	The calculation include the production of photovoltaic lighting
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, equipment 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

Notes: [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, affiliated 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 percent less than for the Low Energy House and about six times less than that is planned by the French thermal regulation (RT2000) and four times less than the German regulative value. (*)Means: total primary energy, equipment included: maximum of 120kWh/(m^2. y)
Source: Authors according to their thermal regulations

Table I.

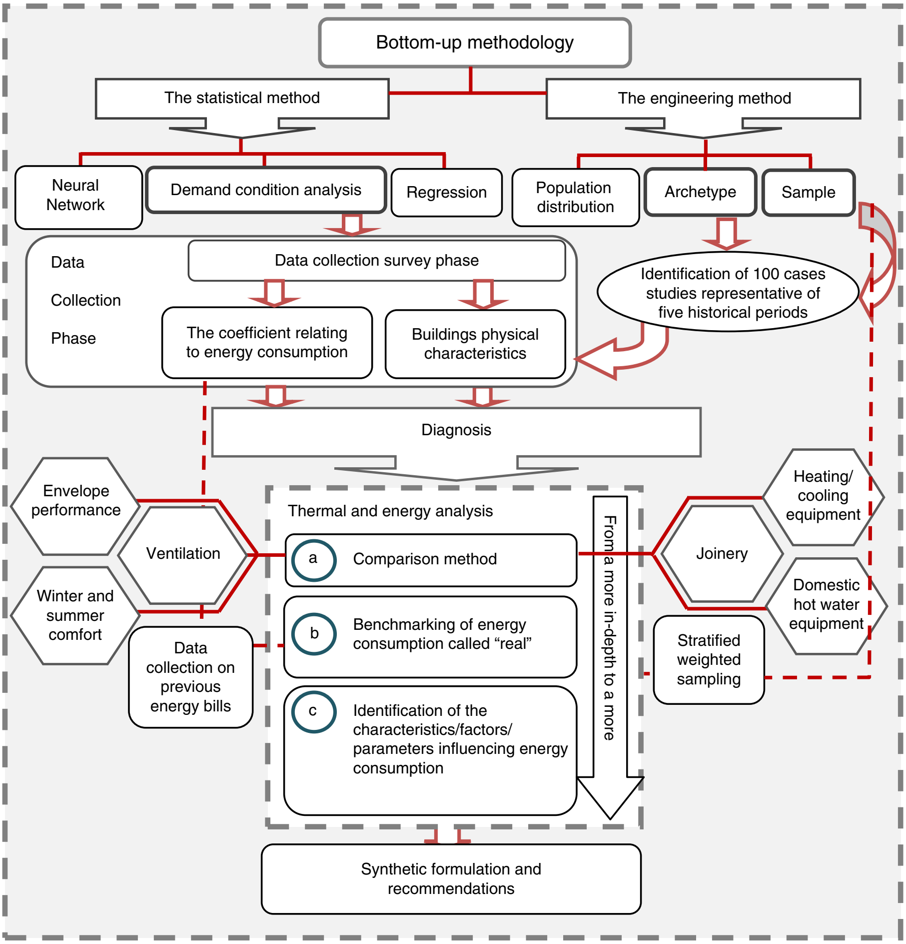


Figure 1.
Logogram of the method adopted in the study

Source: Authors

work was specially carried out for this study because the date of construction of the buildings in Tlemcen is information that did not exist until then. The construction periods chosen are as follows:

- French colonial period: between 1872 and 1938, from 1939 to 1957, from 1958 to 1962; and
- post-independence period: from 1974 to 1989, from 1990 to 2016.

(2) Step 2: a data collection survey phase, using the demand condition analysis technique that evaluates the final energy consumption of different appliances in dwellings. The regression of the total final energy consumption of a dwelling on the list of appliances (which are indicated as a variable) thus determines the coefficient relating to energy consumption. The latter simultaneously represents the level and the rate of use.

(3) Step 3: the development of diagnostics using the physical characteristics of buildings envelopes through the Archetype by period through:
   - identification of sufficient cases (100 dwellings were selected for this purpose) of different studies in terms of size, typology, morphology and technological characteristics to describe the entire residential regional park; and
   - thermal and energy analysis of the cases studied above, using different tools of analysis (benchmarking, energy auditing and simple calculation), from a more in-depth to a more detailed:
     - The method of comparisons between: envelope performance, winter and summer comfort, joinery, ventilation and heating and domestic hot water equipment in each type.
     - Energy consumption called "real" (data collection on previous energy bills by selecting the same number of case in each stratum to allow comparisons thereafter. This is called stratified weighted sampling: each stratum is equalized).
     - Identification, through the above analysis, the strengths and weaknesses of buildings as energy consumers (characteristics/factors/parameters that most influence the energy performance of the dwellings).
   - Synthetic formulation and recommendations to reduce consumption by simple measures.

5. Definition of archetypes by period

In order to analyze the thermal and energy performance of the Tlemcen's multi-storey residential buildings, each was thus classified into a reference family. These families are primarily historical (see Figure 2). The delimitation of each historical period has been established on the basis of: the great historical periods that mark urban history (French colonization, the first and second world wars, the revolution of liberation, independence); urban policy changes and changes in building regulations (Urban Planning Plan, Master Plan for Development and Town Planning, Land Use Plan). In order to establish, by archetype, the classification of buildings in Tlemcen, from the way of building to a given period and the dominant architectural types (passing from the terraced house, multi-family house, the open island of the colonial period to the apartment blocks as towers and bars and the return to the town adjoining of the post-independence period), to establish a method of analysis applicable to all buildings of the same period.

6. Results and discussion

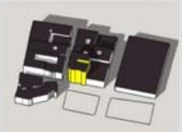
6.1 Thermal analysis of building

6.1.1 Wall/facade performance. The envelope of the building is responsible for the largest contribution that affects the energy used for heating and cooling. The main heating input components are infiltrations as well as conduction losses through the envelope components including walls, roof, floor, slabs, windows and doors (Awadallah, 2011).

Colonial period. The constructions of this period are the most complex from thermal and energy analysis point of view. During this period, the construction methods have evolved rapidly. There are two modes:

(1) The housing before the First World War is characterized by stone load-bearing walls quite thick.

(2) While during the Second World War, constructions are based on concrete frames with brick filling (solid and hollow). And on the eve of independence the

Period	Type of building	Photo	Urban form	Height (m)
1872–1938	HBM housing (*Habitation Bon Marché*: cheap housing)			8–12
1939–1957	Luxury housing			31 (Shops in ground floor)
1958–1962	HLM housing (*Habitation à loyer modéré*: Low-income housing) for Algerians			12–21
1958–1962	HLM housing intended for French			12–16
1974–1980	Prefabricated apartments (towers/bars)			14–20
1980–1989	Prefabricated apartments (bars)			14–20
1990–2000	Social housing			20 (Shops in ground floor)
2000–2016	Promotional housing			20–38 (Shops in ground floor)

Source: Authors

Figure 2.
Architectural features of dwellings built in Tlemcen

constructions are based on concrete frames with filling in double walls of hollow brick. Three main types of envelopes can be listed:

- Between 1872 and 1938: the facades are load bearing, the walls are rather thick (40 cm) and have little thermal bridge (having a thermal resistance

R-value = 0.610 m^2.K/W for exterior walls and a R-value = 0.518 m^2.K/W of roofs and ceilings with small vaults and a R-value = 0.445 m^2.K/W of inclined tile roofs) while the walls overlooking the courtyards are less thick (19 cm) and are characterized by a thermal resistance of 0.438 m^2.K/W.

- Between 1939 and 1957: the constructive system, during this period, is a reinforced concrete structure bearing the facade, with brick filling. The walls are finer (16 cm) and lose on the thermal performance plane (having an R-value = 0.491 m^2.K/W for exterior walls and the R-value = 0.969 K.m^2/W of roofs) while the R-value of concrete parts is 0.425 m^2.K/W.
- Between 1939 and 1957: the constructive system, during this period, is a reinforced concrete structure bearing the facade, with brick filling. The walls are finer (16 cm) and lose on the thermal performance plane (having a R-value = 0.491 m^2.K/W for exterior walls and a R-value = 0.969 K.m^2/W of roofs) while the R-value of concrete parts is 0.425 m^2.K/W.
- Between 1958 and 1962: the constructive system is always a reinforced concrete structure that carries the facade, the filling in double walls of brick with an air gap of 11 cm that has a better inertia with a R-value = 0.649 m^2.K/W for exterior walls and the same thermal characteristics of roofs and ceilings as the previous period.

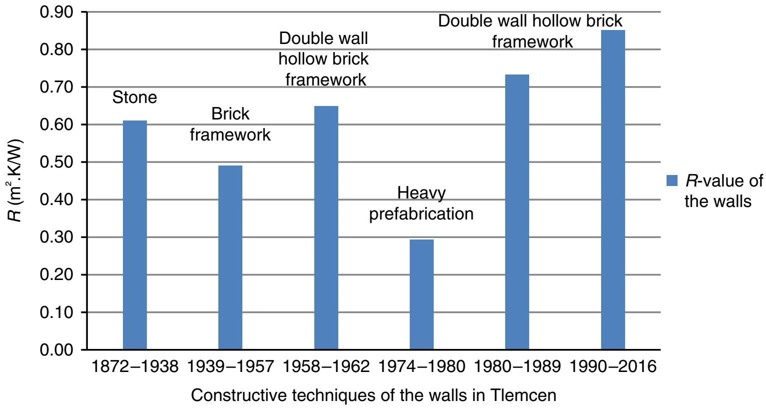
Postcolonial period

- Between 1974 and 1989: the construction during the 1980s has seen the advent of heavy prefabrication (known in France during the 1950s–1960s and rejected as soon as the 1973 oil shock), which has led to deterioration in the quality of the envelopes from the performance point of view. Therefore, we are dealing with what has been a less successful product in Algeria. The envelopes of this period consist of roofs, ceilings and filling of walls with heavy prefabricated elements: tunnel-roofing process (having an R-value = 0.293 m^2.K/W for exterior walls and an R-value of 1.656 m^2.K/W of roofs and ceilings).

  During the same period, other housing projects were constructed using the same process but with hollow brick filling in double walls (having a R-value = 0.733 m^2.K/W for exterior walls).
- Between 1990 and 2016: other housing projects were constructed using the supporting structure (posts-beams) with hollow brick filling in double walls. The envelopes are all based on load-bearing structures. The difference between the buildings will depend on the different materials used. As regards this period, the envelopes consist of: roofs and ceilings in slabs with hollow blocks (16 cm of hollow blocks and 4 cm of reinforced concrete with a layer of expanded polystyrene of 4 cm since the DTR E 4.1 published in 1997) and filling the walls with a double wall of 10 and 15 cm hollow brick separated by a 5 cm air blade.

The performance of the envelopes is rather low since the buildings are not insulated. If we compare the prefabricated construction with that of the supporting structure, we note that the positive influence of the inertia of the materials used in the second envelope (having a R-value = 0.851 m^2.K/W for exterior walls and a R-value = 2.279 m^2.K/W of roofs) is obvious (see Figure 3).

All values of thermal transfer coefficient (U-value) of diagnosed envelopes, shown in Table II, are higher than the maximum values allowed in some developed countries (requiring 0.1 to 0.5 W/m^{2}K for exterior walls and roofs) and developing ones (requiring 0.6 to 1.10 W/m^{2}K for exterior walls and 0.55 to 0.75 W/m^{2}K for roofs). In particular, the U-value



Source: Authors

Figure 3. Thermal resistance of walls according to constructive techniques at Tlemcen

allowed in Oujda (Morocco), whose climate is similar to that of Tlemcen, requires 0.8 W/m^{2}K for exterior walls and 0.65 to 0.75 W/m^{2}K for roofs).

6.1.2 Thermal bridges. According to ISO 10 211, thermal bridge is the part of the envelope of a building where, the otherwise, uniform, thermal resistance is significantly modified either by total or partial penetration of the building envelope by materials having different thermal conductivity, and/or by a change in the thickness of the structure; and/or by a difference between the inner and outer surfaces, as occurs at the wall/floor/ceiling junctions (Penu, 2013).

Between 1872 and 1938. The facade walls, dividing walls and adjoining walls carry the entire building. The floors do not interfere very well with the stability of the building and penetrate minimally in the facades so as not to constrain the load bearing capacity of the facades. The consequence of this construction mode is that the floors do not cause thermal bridges. While the high level of ornamentation of facades and the projections create zones of lower thermal resistance, which will cause thermal leaks in the oriels, balconies, etc.

Between 1939 and 1962. Henceforth, the façade walls are no longer bearers. The framework of buildings, a network of concrete posts and beams, is no longer based on the bearing capacity of the walls. In particular, frontal walls become simple fillings between the beams; thus, multiplying the thermal bridges.

Between 1974 and 2016. The volumetry of the majority of post-independence dwellings is identical or very similar. They are constructed in very simple forms, bars or towers, parachuted into island in an anarchic manner neglecting the location and orientation of buildings in relation to bioclimatic data (sun, prevailing winds, etc.). The treatment of their facades is almost identical, with the exception of colors that change without apparent harmony. The angles of the facade recesses, projections, the facades, window sills, windows and French-window are elements that will create vertical thermal bridges while balconies and loggias, low floors, intermediate floors in a facade in addition to the roof terrace represent places conducive to the diffusion of heat to the outside in winter in the form of horizontal thermal bridges. Assuming that the higher the volume of the building is complex, thermal bridges are important.

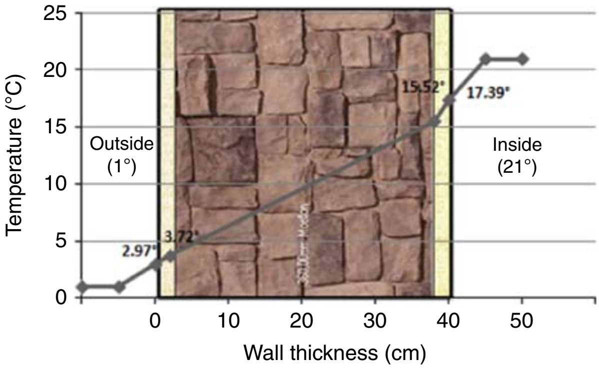
6.1.3 Cold wall effect. Directly related to the thermal comfort and equilibrium of the human, the perceived temperature T, at a relative humidity of 50 percent and in the absence of air movement is equal to the average of the temperature of the air and the temperature of the neighboring walls. The cold wall is a thermal phenomenon that

Table II. Thermal permeability of the walls established according to the composition of the walls

Period		U wall (W/m^2.C°)	Name	Composition of walls Thickness (mm)	Conductivity (W/m.k)	Specific heat (J/kg. k)	Density (Kg/m^3)	Glazing Rates (%)	U-value glazing (W/m^2.C°)	U-value (W/m^2.K) with solar gain South	East/West	North
1872–1938	Street	1.639	Lime mortar	20	0.87	1,080	1,800	30	5,894	2.8–3.7	3.7–4.6	4.6–5.6
			Stone	360	1.00	936	1,800					
			Internal plaster coating	20	0.35	936	1,000					
	Court	2.285	Lime mortar	20	0.87	1,080	1,800					
			Brick	150	0.80	936	1,800					
			Internal plaster coating	20	0.35	936	1,000					
1939–1957	Street	2.035	Ciment mortar	20	1.40	1,080	2,200	40				
	and		Hollowed brick	120	$R = 0.25\,m^2.K/W$							
	court		Internal plaster coating	20	0.35	936	1,000					
	Street	2.351	Ciment mortar	20	1.4	1,080	2,200					
	and		Reinforced concrete	460	2.5	1,000	2,400					
	court		Internal plaster coating	20	0.35	936	1,000					
1958–1962	Street	1.542	Ciment mortar	20	1.40	1,080	2,200	40				
	and		Hollowed brick	100	$R = 0.20\,m^2.K/W$							
	court		Air gap	110	$R = 0.15\,m^2.K/W$							
			Hollowed brick	50	$R = 0.10\,m^2.K/W$							
			Ciment mortar	20	1.40	1,080	2,200					
1974–1989	Street	3.408	Ciment mortar	20	1.40	1,080	2,200	15				
	and		Prefab. concrete panel	130	2.50	1,000	2,400					
	court		Internal plaster coating	02	0.35	936	1,000					
	Street	1.363	Ciment mortar	15	1.40	1,080	2,200	15				
	and		Hollowed brick	100	$R = 0.20\,m^2.K/W$							
	court		Air gap	50	$R = 0.11\,m^2.K/W$							
			Hollowed brick	100	$R = 0.20\,m^2.K/W$							
			Internal plaster coating	15	0.35	936	1,000					
1990–2016	Street	1.174	Ciment mortar	20	1.40	1,080	2,200	15				
	and		Hollowed brick	150	$R = 0.30\,m^2.K/W$							
	court		Air gap	50	$R = 0.11\,m^2.K/W$							
			Hollowed brick	100	$R = 0.20\,m^2.K/W$							
			Internal plaster coating	02	0.35	936	1,000					

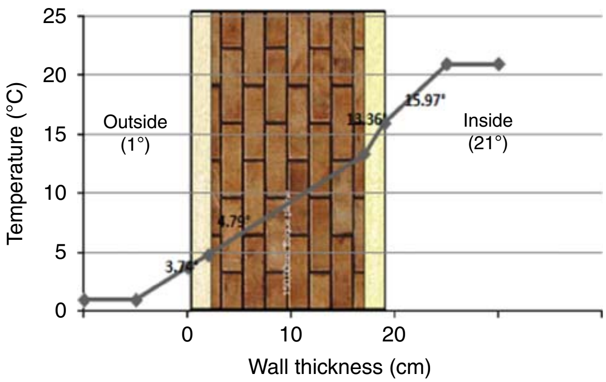
Source: Authors according to CNERIB (1998) occurs in houses that are not or poorly insulated and that is particularly unpleasant for their occupants. This effect is manifested by cold temperature felt behind the wall, resulting in an overall drop in temperature of the house, which inevitably results in an increase in energy expenditure. To illustrate this phenomenon, a simple calculation of the evolution of the temperature at the level of the wall for an outside temperature of 1°C (base outdoor temperature in Tlemcen which is classified in climatic zone "B" (CNERIB, 1998)) and an internal temperature of 21°C (considered in DTR C. 3-2 as the basic interior temperature (CNERIB, 1998)).

In the case of dwellings constructed between 1872 and 1938, a temperature on the inner walls of 17.39°C is observed. The phenomenon of cold wall remains quite moderate here because of the chosen materials (masonry and plaster coating) (see Figure 4) and a temperature on the walls overlooking the courtyards of 15.97°C. The cold wall phenomenon is very pronounced here (see Figure 5).



Source: Generated using Excel Template by authors according to simple calculation results + wall photo using DesignBuilder© Software, 2017

Figure 4.
Effect of cold wall on a 40 cm stonewalls



Source: Generated using Excel Template by authors according to simple calculation results + wall photo using DesignBuilder© Software, 2017

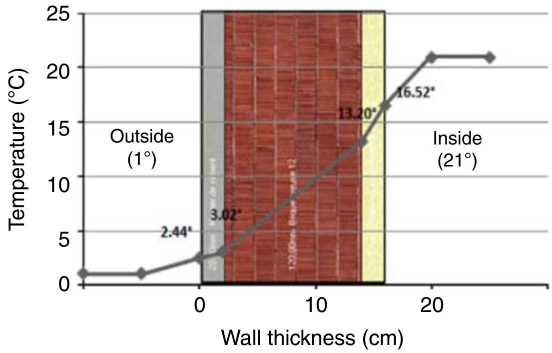
Figure 5.
Effect of cold wall on a wall of 19 cm full brick

In the case of dwellings constructed between 1939 and 1957 with reinforced concrete framing and hollow brick filling, a temperature on the inner walls of 16.52°C was observed. The cold wall phenomenon is quite pronounced here (see Figure 6). While, the temperature on the inner face of the reinforced concrete walls is 15.83°C. The cold wall phenomenon is also very pronounced here (see Figure 7).

In the case of dwellings constructed between 1958 and 1962 with a reinforced concrete frame and a hollow brick filling with a large air blade, the surface temperature of the walls is 17.61°C. Lower even as the lower threshold of the comfort zone (see Figure 8).

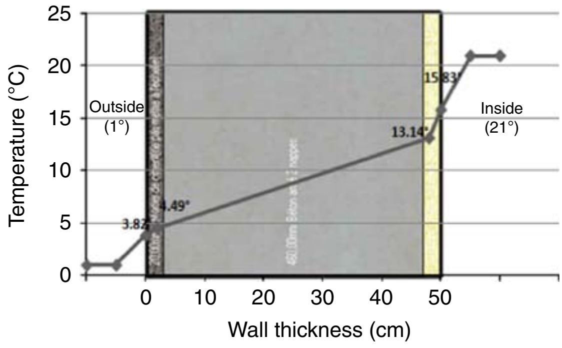
In the case of dwellings built from 1974 to the present day, three main types of facades are studied here:

(1) Framework with filling in heavy prefabricated, case of the process of the formwork called "tunnel": the temperature is 13.5°C. It is pretty low. The effect of the cold wall is very pronounced and the feeling of discomfort in the inhabitants will be strong. However, it is evident that a cold wall effect is felt at the frame joints of the prefabricated module (see Figure 9).



Source: Generated using Excel Template by authors according to simple calculation results + wall photo using DesignBuilder© Software, 2017

Figure 6. Effect of cold wall on a wall of 16 cm hollow brick



Source: Generated using Excel Template by authors according to simple calculation results + wall photo using DesignBuilder© Software, 2017

Figure 7. Effect of cold wall on a wall of 50 cm in reinforced concrete

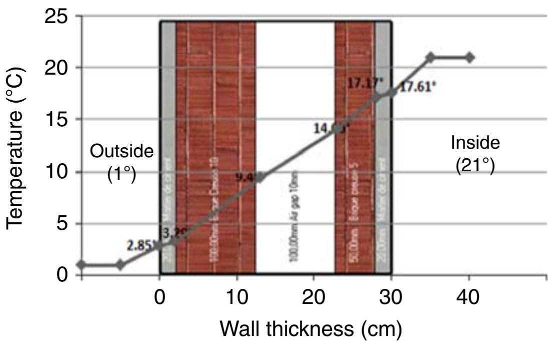


Figure 8.
Effect of cold wall on a 30 cm double wall hollow brick walls (5 cm/10 cm) separated from 11 cm of uninsulated air

Source: Generated using Excel Template by authors according to simple calculation results + wall photo using DesignBuilder© Software, 2017

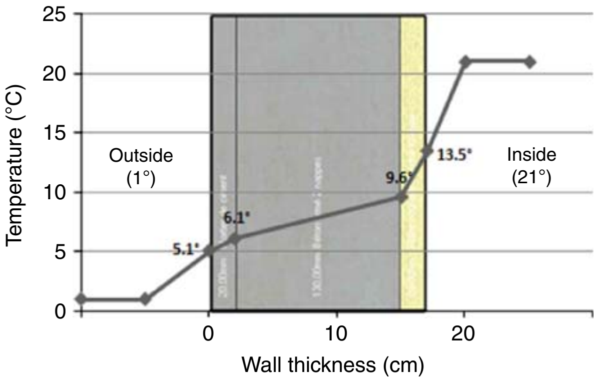


Figure 9.
Effect of cold wall on a 17 cm wall of uninsulated reinforced concrete

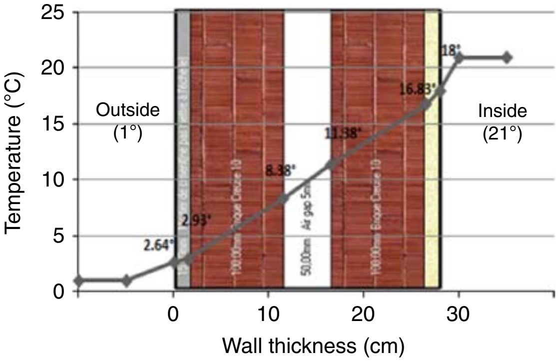
Source: Generated using Excel Template by authors according to simple calculation results + wall photo using DesignBuilder© Software, 2017

(2) Frame with hollow brick filling (10 cm/10 cm) and 5 cm of air gap: the surface temperature of the walls is 18°C. This is higher than in the previous case, and it is near the low threshold of the comfort zone (see Figure 10).

(3) Frame with hollow brick filling (10 cm/15 cm) and 5 cm of air gap: the surface temperature of the walls is 18.42°C. This is near the low threshold of the comfort zone too (see Figure 11).

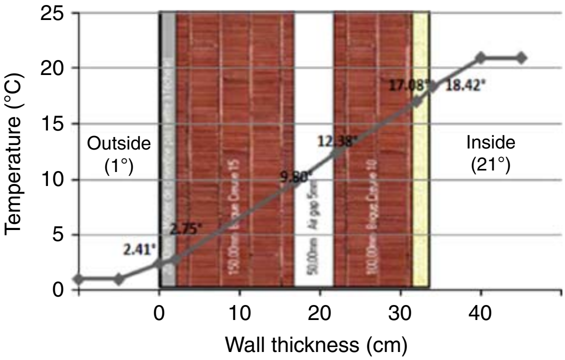
6.1.4 Joinery. The multi-storey residential buildings were generally provided with wooden windows with single glazing and an occultation in shutters. These elements are generally a source of heat loss as well as sound gene. From the years 2000, the windows are aluminum or PVC but always with a simple glazing. The double glazing in the housing is not yet generalized in Algeria – except in some cases of housing of high standing – because of its high price.

6.1.5 Summer comfort. Summer comfort is a new challenge in the face of climate change. The increase in demand for electric power during the summer observed, in recent years in



Source: Generated using Excel Template by authors according to simple calculation results + wall photo using DesignBuilder© Software, 2017

Figure 10.
Effect of the cold wall on a 28 double wall hollow brick walls (10 cm/10 cm) separated from 5 cm of uninsulated air



Source: Generated using Excel Template by authors according to simple calculation results + wall photo using DesignBuilder© Software, 2017

Figure 11.
Effect of the cold wall on a wall of 34 cm in double hollow brick walls (10 cm/15 cm) separated from 5 cm of uninsulated air

Tlemcen, can be reasonably explained by the increasing use of air conditioning. This can be explained by summer overheating, caused by:

- Non studied orientation.
- Low inertia of majority of buildings. The calculation methods used in Algerian regulation are simpler. This is a positive point according to Grundström *et al.* (2003), since it allows to take advantage of the thermal inertia of a building which is a very important factor given the type of climate and existing buildings in Algeria.
- Insufficient night ventilation caused by the design of non-traversing units (generalized in social housing).
- Closed kitchen loggias by single glazed windows to increase kitchen surfaces and to protect them from bad weather.

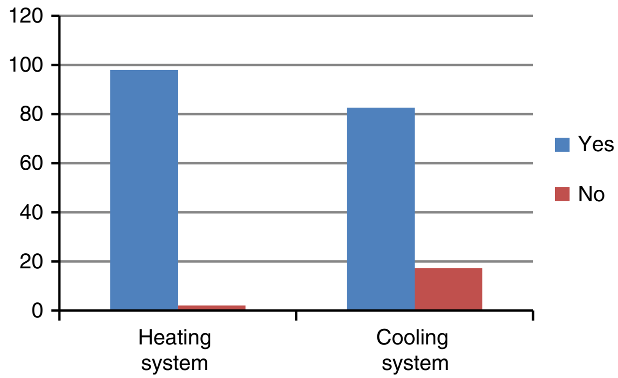
6.1.6 Ventilation. Ventilation is a legal obligation that preserves the "health" of buildings and their occupants. In Algeria as in Tlemcen, most homes do not have a ventilation system and are ventilated by window openings and leaks in the envelope. For this type of natural ventilation, it is not possible to predict the minimum rate of air renewal in dwellings. First, infiltration differs over time depending on changing wind speed and direction, resulting from the pressure difference between the facades. Second, the user behavior (opening/closing windows) strongly affects the air changes (Rosenland *et al.*, 2005). In summer, the windows are mostly open, but in winter, the windows are open just at the time of cleaning. As a result, occupants tend to keep the doors closed during periods of extreme cold. This behavior is detrimental to the quality of the air and regularly causes drama. They are open during the autumn and spring days.

A regulation, in the form of DTR C 3-31, developed in 2005 by the CNERIB, provides the general principles that should be adopted when designing natural ventilation systems. And states that ventilation must be permanent at least during the period when the outside temperature makes it necessary to keep the doors closed. The choice of general ventilation as a reference system responds to the desire for energy efficiency, by exhausting the possibilities of the air as much as possible before evacuating it.

6.1.7 Heating and cooling equipment. The buildings built before World War II were designed with chimneys in the main rooms and ducts for connecting stoves. These chimneys also contributed to the design of the roofs of the buildings. The heating energy was at that time wood and charcoal. Currently, these units are equipped with individual gas or electric heaters. The dwellings built at the beginning of the post-independence period were equipped with fuel oil or butane gas stoves. Currently, most of the dwellings are heated (98 percent of the chosen sample). In total, 82 percent of these are connected to the natural gas network and are equipped with natural gas radiators (individual systems). Some apartments (18 percent) are equipped by individual gas or electric boilers. No air-conditioning placement, but it has been arranged in some ones by individual electric air conditioners (exp: split) (83 percent of the chosen sample) (see Figure 12). These systems are placed primarily in the corridor or lobby (see Figure 13).

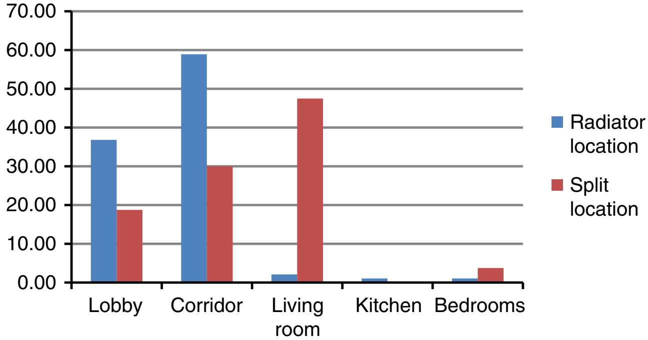
Heating, gas and electricity are all measured individually. The advantage of individual billing systems is to make the occupants responsible, since everyone pays for what they consume, which results in the energy consumption being lowered.

6.1.8 Domestic hot water equipment. The domestic hot water is mainly produced by standalone gas water heaters (nearly 77 percent of the chosen sample). The use of electricity to heat water, as: gas boiler, electric boiler, electric water heater, etc., represents only 23 percent of the chosen sample (see Figure 14).



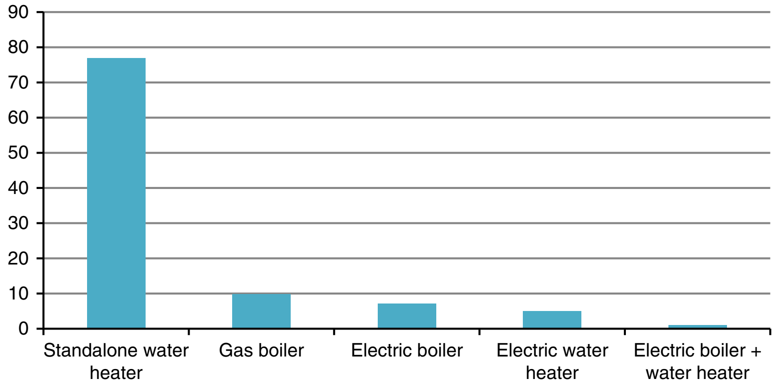
Source: Authors according to the data collection survey, 2017

Figure 12.
Heating and cooling systems of dwellings in Tlemcen



Source: Authors according to the data collection survey, 2017

Figure 13.
Location of heating and cooling systems in dwellings in Tlemcen



Source: Authors according to the data collection survey, 2017

Figure 14.
Domestic hot water production equipment in Tlemcen

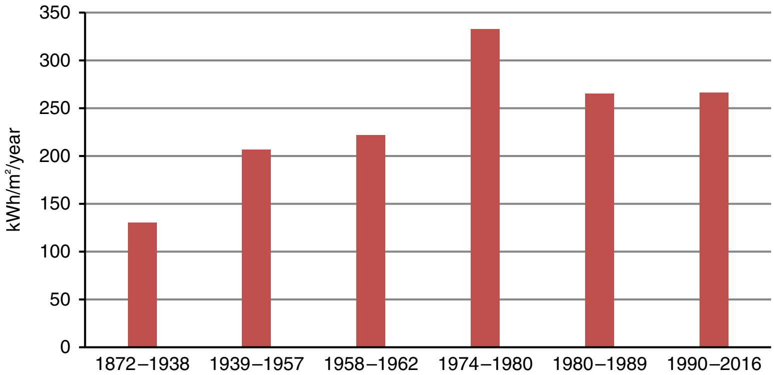
6.2 Benchmarking of energy consumption in dwellings of different periods

An average value of the "real" energy consumption collected from the previous energy bills of dwellings, built between 1872 and 1938, is estimated at 130kWh/m^2/year, with a range of ±50kWh/m^2/year depending on the morphological configuration of the building. This is above the upper threshold of the 2008 Tunisian thermal regulation and that of the BBC Renovation label and twice the upper thresholds of the two regulations of 2012.

The same thing for dwellings, built between 1939 and 1962, with an average value of more than 200kWh/m^2/year. But it remains below the requirements of HPE renovation for buildings built after 1948.

The consumption of dwellings built between 1980 and 1990 and those built after the 1990s till now is more than 250kWh/m^2/year. This is at the upper threshold of the French regulation of 2005 and above that of the Heritage Houzing certification, Heritage Houzing and environment reserved to owners of multi-story buildings.

Dwellings built between 1974 and 1989 have exceeded the threshold of 300kWh/m^2/year. The figure of more than 300kWh/m^2/year expresses a very high level of consumption. This is equivalent to 20 times the requirements of German Passivhaus of 1990 and two and a half times the maximum of French Passive House of 2007. So, the most energy-consuming buildings found in Tlemcen are those built during the years 1974–1989. The low inertia and full-time use of the individual boiler system pulled up the consumption of the inhabitants (see Figure 15).



Source: Authors according to estimates achieved from bills gatherings, 2017

Figure 15. Energy consumption of multi-storey residential buildings in Tlemcen (heating + domestic hot water)

7. Conclusion

In this study, we aim at multi-storey residential buildings representative of the different periods of urbanization of the city of Tlemcen. An evaluation of the thermal and energy performance of the existing envelopes in the residential stock, using a bottom-up approach, was carried out through combination of building physics and empirical data from housing surveys, as indicated in Wilson and Swisher (1993). This improves the characterization of the multi-storey building on this town to obtain consistent results as recommended by Sousa Monteiroa *et al.* (2017).

The contribution of this study is the creation of an Algerian database to collect information about the existing housing stock and analyze it. This gives the modelers tools to estimate energy use in dwellings in the past, the present and the future and assists technicians in the priorities of intervention attempts. This appropriate methodology can be applicable to different climatic zones.

A sample of 100 case studies have been selected and analyzed in depth, in order to highlight precisely the typological and technological problems, shown in Table III, having the greatest impact on thermal and energy performance of dwellings.

So, it is in the gathering of data and the development of a method adequate to their analysis that most of our work resides. In this sense, our study is, above all, a work of testing the proposed method. Nevertheless, the application of this method to the sources we have listed, especially (Parekh, 2005; Garrido-Soriano, 2010; Garrido-Soriano *et al.*, 2012; Ivancic *et al.*, 2014; The InnoCons Project, 2012; Mata *et al.*, 2014; EPISCOPE Project Team *et al.*, 2016) has led us to a certain number of observations that are presented as the conclusions of this work.

This study also showed that we cannot talk about thermal rehabilitation of multi-family buildings before inventorying and diagnosing different types of envelopes that exist in the housing stock using a bottom-up approach. However, it should be noted that in the context of energy audits, the parameters are unclear, or tainted by high uncertainty and lack of transparency in quantifying the impact of occupant behavioral factors on energy consumption, as has reported Ouahab (2015), particularly due to variations of execution of works. Moreover, the sources of uncertainty are numerous, e.g. a large part of housing is heated and refreshed, measurement errors (related to tools or their use), imprecision of visual collections, impossible access or lack of updated data. This highlights the need for a particular participatory approach to carry out rehabilitation operations in an occupied environment. Specific social approaches to rehabilitation need to be developed in the particular context of each case.

Period	Highlights of the building	Weaknesses of the building
1872–1938	Good thermal inertia Few thermal bridge at floor level Crossing apartments allowing good ventilation	Cold wall phenomenon Natural ventilation Old joinery and glazing Thermal bridges at the level of the projections and the ornamental elements of the facades
1939–1957		Cold wall phenomenon Thermal bridges caused mainly by the heterogeneity of the materials constituting the walls of the facades and at the level of the projections
1958–2016	Absence of heritage value that allows retrofitting (external insulation) Crossing apartments allowing good ventilation	Inefficient facades notably those of prefabricated housing Winter discomfort associated with cold wall effect especially in prefabricated dwellings The non-crossing apartments difficult to ventilate causing moisture damage Thermal bridges caused mainly by balconies and loggias Unstudied orientation Summer overheating caused by low inertia and difficulty of night ventilation Heating with individual system causing the temperature variation between the rooms and the oxygen depletion in the apartment

Source: Authors

Table III. Strengths and weaknesses of the building

Also, it was found that dwellings, built between 1872 and 1920, had better thermal and energy performance than the five periods selected with a consumption index of 130kWh/m^2/year. On the other hand, those built between 1974 and 1989 are the most energy intensive, with a consumption index of 300kWh/m^2/year. But also, they are the easiest to comply with thermal regulations.

Therefore, given the importance of the existing building stock, thermal rehabilitation is more than necessary. This leads to the application of thermal regulation and its evolution toward local labeling, such as Tunisian regulations. This is possible by taking into account the socio-economic context.

A first set of actions must be taken, as a priority, through simple energy efficiency measures and a case-by-case approach:

(1) Reduced air tightness of the envelope by controlling the air permeability of windows and developing a lifestyle culture of environmental awareness and user awareness.

(2) Improvement of the thermal insulation of the envelope (roofing, walls and windows):

- The case of the absence of heritage value makes it possible to consider ambitious thermal rehabilitation measures by using thermal insulation from the outside to eliminate thermal bridges.
- In the case where walls of frontages possessing a real heritage value (ornamentation, marble, earthenware, etc.) insulation from the inside will be rarely advised. It is preferable to use an insulating inner coating that will improve somewhat the thermal performance of envelopes and comfort of the internal environment.
- In the case of walls overlooking the courtyards which have no heritage value, it is possible to implement thermal insulation from the outside.
- Use of double glazing.
- Increasing south facing glazed surfaces without exceeding the rate appropriate to the climate.

- Simple ways exist to avoid very uncomfortable situations, even without heating/cooling, such as: shading device sized properly, free-cooling, replacement of obsolete equipment, etc.

(3) Public awareness and economic encouragement through individual measures of all types of energy.

(4) The pre-financing of thermal rehabilitation operations for private customers is a point that must be examined as soon as the market has reached a sufficient size for the credit institution to be available.

(5) Innovative financial mechanisms are to be imagined: taxes penalize large consumer buildings and feed a fund that grants a premium to those who go beyond regulation.

Finally, the scope of this study can be shared with North Africa countries with a similar geographic, social, cultural and economic context: from Egypt to Morocco. These countries share a common cultural context and their economic situations are undergoing similar developments.

References

Awadallah, T.-S. (2011), "Infill-building's, according to orientation in Amman-Jordan", unpublished master's thesis, Faculty of Graduate Studies, The University of Jordan Archives, Amman, p. 62.

Belpoliti, V. and Bizzarri, G. (2015), "A parametric method to assess the energy performance of the social housing stock and simulate suitable retrofit scenarios: an Italian case study", *Energy and Buildings*, Vol. 96 No. 11, pp. 261-271.

CNERIB (1998), "Document technique réglementaire DTRC3-2 – Réglementation thermique des bâtiments d'habitation: règles de calcul des déperditions calorifiques", Facicule 1, Centre National d'Etudes et de Recherche Intégrée du Bâtiment, Algiers, pp. 11-71.

Csoknyai, T., Hrabovszky-Horváth, S., Georgiev, Z., Jovanovic-Popovic, M., Stankovic, B., Villatoro, O. and Szendrő, G. (2016), "Building stock characteristics and energy performance of residential buildings in Eastern-European countries", *Energy and Buildings*, Vol. 132 No. 23, pp. 39-52.

Dascalaki, E.-G., Droutsa, K.-G., Balaras, C.-A. and Kontoyiannidis, S. (2011), "Building typologies as a tool for assessing the energy performance of residential buildings – a case study for the Hellenic building stock", *Energy and Buildings*, Vol. 43 No. 12, pp. 3400-3409.

Denker, A. and El Hassar, S.-K., et un groupe d'experts sur l'efficacité énergétique et la durabilité sous la direction de Baradiy, S. dans le cadre de la Coopération allemande au développement (GIZ) avec l'Agence pour la promotion et la rationalisation de l'utilisation de Énergie (APRUE) (2014), *Guide pour une construction écoénergétique en Algérie*, Deutche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH, Allemagne, Alger, pp. 19-21.

Djebbar, K.-B., Salem, S. and Mokhtari, A. (2018), "A multi-objective optimization approach of housing in Algeria. A step towards sustainability", *Urbanism. Arhitectură. Construcţii*, Vol. 9 No. 2, pp. 131-158.

EPISCOPE Project Team, Wittchen, K., Kragh, J., Diefenbach, N., Loga, T., Arcipowska, A., Rakuščeк, A., Zavrl, M.-Š., Altmann, N., Hulme, J., Riley, J., Dascalaki, E., Balaras, C., Cuypers, D., Van Holm, M., Corrado, V., Ballarini, I., Vimmr, T., Hanratty, M., Sheldrick, B., Roarty, C., Soknyai, T., Szendrő, G., Hrabovszky-Horváth, S., Ortega, L., Serghides, D., Katafygiotou, M., Nieboer, N., Filippidou, F., Rochard, U., Shanthirabalan, S., Brattebö, H., Popovic, M.J. and Ignjatovic, D. (2016), "Application of Energy Performance Indicators for residential building stocks – experiences of the EPISCOPE project", Energy Performance Indicator Tracking Schemes for the Continuous Optimisation of Refurbishment Processes in European Housing Stocks, available at: http://episcope.eu/fileadmin/episcope/public/docs/reports/EPISCOPE_Indicators_ConceptAndExperiences.pdf (accessed August 1, 2016).

Famuyibo, A., Duffy, A. and Strachan, P. (2012), "Developing archetypes for domestic dwellings – an Irish case study", *Energy and Buildings*, Vol. 50 No. 7, pp. 150-157.

Garrido-Soriano, N. (2010), "Eficiència i certificació energètica d'edificis residencials", Departament de Projectes d'Enginyeria, Universitat Politècnica de Catalunya, Terrassa.

Garrido-Soriano, N., Rosas-Casals, M., Ivancic, A. and Álvarez-del Castillo, M.D. (2012), "Potential energy savings and economic impact of residential buildings under national and regional efficiency scenarios. A Catalan case study", *Energy and Buildings*, Vol. 49 No. 6, pp. 119-125.

Gossard, D., Lartigue, B. and Thellier, F. (2013), "Multiobjective optimization of a building envelope for thermal performance using genetic algorithms and artifcial neural network", *Energy and Buildings*, Vol. 67 No. 12, pp. 253-260.

Grundström, K., Johansson, E., Mraissi, M. and Ouahrani, D. (2003), "Climat et Urbanisme – La Relation entre le Confort Thermique et la Forme du Cadre Bâti", Report No. 8, Housing Development and Management, Laboratoire Public d'Essais et d'Etudes, Lund University, Lund.

Hrabovszky-Horváth, S., Pálvölgyi, T., Csoknyai, T. and Talamon, A. (2013), "Generalized residential building typology for urban climate change mitigation and adaptation strategies: the case of Hungary", *Energy and Buildings*, Vol. 62 No. 7, pp. 475-485.

InnoCons (2012), "Eficiencia energetica en la rehabilitación de edificios", available at: www.innocons.cat/99 pdf/2012/eficiencia energetica rehabilitacion.pdf

Ivancic, A., Lao, J., Salom, J. and Pascual, J. (2014), "Local energy plans: a way to improve the energy balance and the environmental impact of the cities: case study of Barcelona", *ASHRAE Transactions*, Vol. 110 No. 1, pp. 583-591.

Manyes, A., Sisó, L. and Salom, J. (2013), "Block level study and simulation for residential retrofitting", *Proceedings of BS2013: 13th Conference of the International Building Performance Simulation Association (IBPSA), IBPSA*, *Chambéry*, *August 26–28*, pp. 88-95.

Mata, É., Sasic Kalagasidis, A. and Johnsson, F. (2013), "A modelling strategy for energy, carbon, and cost assessments of building stocks", *Energy and Buildings*, Vol. 56 No. 1, pp. 100-108.

Mata, É., Sasic-Kalagasidis, A. and Johnsson, F. (2014), "Building-stock aggregation through archetype buildings: France, Germany, Spain and the UK", *Building and Environment*, Vol. 81 No. 11, pp. 270-282.

ME (2017), "Bilan énergétique national pour l'année 2016", Ministère de l'Énergie, pp. 19-21, available at: www.energy.gov.dz/francais/uploads/2017/Bilans_et_statistiques_du_secteur/Bilan_Energetique_National/Bilan_Energitique_National_2016_last.pdf (accessed November 19, 2017).

Ortiz, J., Fonseca, A., Salom, J., Garrido, N., Fonseca, P. and Russo, V. (2016), "Comfort and economic criteria for selecting passive measures for the energy refurbishment of residential buildings in Catalonia", *Energy and Buildings*, Vol. 110 No. 1, pp. 195-210.

Ortiz, J., Fonseca, A., Salom, J., Russo, V., Garrido, N. and Fonseca, P. (2015), "Optimisation of energy renovation of residential sector in Catalonia based on comfort, energy and cost", *Proceedings of BS2015: 14th Conference of International Building Performance Simulation Association*, *Hyderabad*, *December 7–9*, pp. 2125-2132.

Ouahab, A. (2015), "Les gisements d'économie d'énergie et des émissions de CO_2 à l'horizon 2050 dans le secteur résidentiel algérien", *Revue des énergies renouvelables*, Vol. 18 No. 4, pp. 667-682.

Parekh, A. (2005), "Development of archetypes of building characteristics libraries for simplified energy use evaluation of houses", *9th International Conference, IBPSA*, *August 15–18*, *Montréal*, pp. 921-928.

Penu, G. (2013), *La thermique du bâtiment: cahiers techniques en 36 fiches-outils*, Dunod, Paris, p. 144.

Sénit, C.-A. (2008), "L'efficacité énergétique dans le secteur résidentiel: une analyse des politiques des pays du Sud et de l'Est de la Méditerranée PSEM", IDDRI – Idées pour le débat N° 14/2008, Changement Climatique, Paris, pp. 33-35.

Sousa Monteiroa, C., Pinaa, A., Cerezob, C., Reinhartb, C. and Ferrão, P. (2017), "The use of multi-detail building archetypes in urban energy modelling", *8th International Conference on Sustainability in Energy and Buildings, SEB-16 Energy Procedia*, *Turin*, *September 11–13*, pp. 817-825.

Swan, L.-G. and Ugursal, V.-I. (2009), "Modeling of end use energy consumption in the residential sector: a review of modeling techniques", *Renewable and Sustainable Energy Reviews*, Vol. 13 No. 8, pp. 1819-1835.

TABULA Project Team, Loga, T., Diefenbach, N., Stein, B., Dascalaki, E., Balaras, C.-A., Droutsa, K., Kontoyiannidis, S., Šijanec-Zavrl, M., Rakušcek, A., Corrado, V., Corgnati, S., Ballarini, I., Roarty, C., Hanratty, M., Sheldrick, B., Van-Holm, M., Renders, N., Popiolek, M., Kwiatkowski, J., Amtmann, M., Vimmr, T., Villatoro, O., Wittchen, K.-B., Kragh, J., Despretz, H., Georgiev, Z., Spets, K., Ortega, L., Lanzarote, B.-S., Jovanovic-Popovic, M. and Ignjatovic, D. (2012), "Typology approach for building stock energy assessment. Main results of the TABULA project – final project report", Institut Wohnen und Umwelt GmbH, Rheinstr, 65/D-64295 Darmstadt, available at: www.buildingtypology.eu/downloads/public/docs/report/TABULA_FinalReport.pdf (accessed February 6, 2017).

Thibault, H.L. and Andaloussi, H. (2011), "L'efficacité énergétique dans le bâtiment en Méditerranée", Plan Bleu, Futuribles, n°376, -juillet-août 2011, Paris, pp. 47-60.

Wilson, D. and Swisher, J. (1993), "Exploring the gap: top-down versus bottom-up analyses of the cost of mitigating global warming", *Energy Policy*, Vol. 21 No. 3, pp. 249-263.

Further reading

CNERIB (2006), "Document Technique Réglementaire D.T.R. C3.31, Ventilation naturelle: Locaux à usage d'habitation", Centre National d'Etudes et de Recherches Intégrées du Bâtiment, Algiers, pp. 15-18.

Filippín, C., Ricard, F. and Flores-Larsen, S. (2013), "Evaluation of heating energy consumption patterns in the residential building sector using stepwise selection and multivariate analysis", *Energy and Buildings*, Vol. 66 No. 11, pp. 571-581.

Ganesan, K., Prashant, B., Kira, C., Saswati, C., Pierre, J. and Sameer, M. (2014), "Baseline scenario of energy consumption of urban multi-storey residential buildings in India", *30th International Plea Conference, CEPT University*, *Ahmedabad*, *December 16–18*, pp. 1-8.

Kildsgaard, I., Jarnehammar, A., Widheden, A. and Wall, M. (2013), "Energy and environmental performance of multi-story apartment buildings built in timber construction using passive house principles", *Buildings*, Vol. 3 No. 1, pp. 258-277, doi: 10.3390/buildings3010258.

Kragh, J. and Wittchen, K.-B. (2014), "Development of two Danish building typologies for residential buildings", *Energy and Buildings*, Vol. 68 No. 1, pp. 79-86.

Loga, T., Stein, B. and Diefenbach, N. (2016), "TABULA building typologies in 20 European countries – making energy-related features of residential building stocks comparable", *Energy and Buildings*, Vol. 132 No. 23, pp. 4-12.

Melo, A.-P., Fossati, M., Versage, R.-S., Sorgato, M.J., Scalco, V.-A. and Lamberts, R. (2016), "Development and analysis of a metamodel to represent the thermal behavior of naturally ventilated and artificially air-conditioned residential buildings", *Energy and Buildings*, Vol. 112 No. 3, pp. 209-221.

Rosenlund, H., Jianqing, H. and Guofeng, S. (2005), "Housing design for lower domestic energy use: exemplified by multi-storey buildings in Beijing", *Building Issues*, Vol. 15 No. 1, pp. 1-24.

Stefanović, A. and Gordić, D. (2016), "Modeling methodology of the heating energy consumption and the potential reductions due to thermal improvements of staggered block buildings", *Energy and Buildings*, Vol. 125 No. 15, pp. 244-253.

Corresponding author
Khadidja El-Bahdja Djebbar can be contacted at: kh_djebbar@yahoo.fr