Standard Energy Renovation at the Urban Scale in the Moroccan Context

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Abstract. As part of a participatory and pluralist approach towards the implementation of future energy policy, this study aims to address the lack of studies on urban-scale energy renovation in Morocco. We aim to provide a methodological framework to support decision-making processes related to energy-conscious urban planning strategies. The proposed methodological framework is based on a bottom-up approach in a multi-scale GIS environment. It combines physical and statistical methods to split up the building stock market into different archetypes. Simulating a dozen archetypes instead of thousands of buildings presents a good compromise of accuracy and low cost. The results of this simulation can subsequently be generalized to the entirety of the rest of the buildings. The town of M'diq in Northern Morocco is the case study for the present article, and it has shown that the implementation of large scale energy renovation can achieve an energy saving up to 52.72% in the standard of Thermal Building Regulations in Morocco (RTCM) scenario.

Keywords: Archetype · Energical simulation · Energy retrofit · GIS · Urban modelisation · RTCM

1 Introduction and Context

Morocco has set up a proactive national energy strategy in order to support strong economic growth within a sustainable development framework. Given that the country imports over 90% of its steadily increasing energy needs, the main objective of the national strategy is therefore to reduce this heavy energy dependency on imports by achieving 15% energy savings by 2030 [1].

The urbanization rate has reached 63.9% in the last 50 years [2], population growth and urban sprawl have led to an increase in energy consumption, which is up by 33% in this sector (7% and 26% for the tertiary and residential sectors, respectively). Faced with these challenges, the construction sector alone can attain energy savings of up to 40% [3].

Newly constructed buildings account for an annual rate of 1.5–2% for the entire building stock, indicating that the renewal of all existing buildings will take roughly 50–100 years or more. This implies that the current building stock will continue to be part of the urban construction environment for decades [4]. In terms of policy, there is

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no national renovation strategy in the works apart from the "Green Mosques" initiative [5] and the 2019 policy of mandatory energy audits in the industrial sector [6, 7] which recommends ISO 50001 compliant energy efficiency measures. This highlights the necessity of initiating large scale energy renovation strategies for buildings in order to support the energy transition and reduce energy consumption and greenhouse gas emissions in the urban sector.

In terms of regulation, the decree of general construction establishing building performance standards (RTCM) was passed and approved in 2015. Buildings have to fulfill minimum efficiency and performance thresholds (thermal insulation, building orientation, construction materials etc.) according to their geographic location in order to achieve the following objectives: 1) Reduce heating and air-conditioning requirements 2) Improve thermal comfort 3) Reduce the national energy bill 4) Reduce greenhouse gas emissions [8].

The decree stipulates that these thermal regulations should be considered during the process of granting construction permits. It is only being partially applied, however [9], due to the fact that its implementation is not being backed up by any legislation or definition of the procedures for carrying out technical inspections or measures taken to penalize non-compliance with the decree [10]. The 2020 joint order of the interior and urban planning ministries requires that the technical note of the energy performance regulations becomes the centerpiece of any construction permit application. An architect is therefore required to provide the note in order to confirm the building's conformity to the regulations. Nevertheless, the current energy efficiency measures are not sufficient to reach the energy and climate objectives that were set [11].

The issue of energy efficiency of existing buildings is a major factor given the size of building stock. Yet, the thermal regulations only apply to new buildings [12]. Consequently, its impact will be relatively limited in spite of the urgency of regulating the existing building stock as well [13].

In light of this situation, public policy is called upon to expand the existing thermal regulations to all types of buildings, whether newly constructed or not, to set up a roadmap for the energy renovation of these buildings, to simplify the modernization process of the building stock and increase the prevalence of renewable energies in the urban environment.

Thus, this work is motivated by the considerable lack of large scale urban energy renovation strategies within the country's energy policies. Consequently, it is necessary to support the development of new approaches and urban modernization methods by laying the groundwork for future additions or amendments to the existing regulations.

This paper seeks to explore answers for the following question: How can one evaluate the impact of large scale (district or city-level) energy retrofit strategies on heating and air-conditioning demand? What savings should be expected in a scenario of renovations based on the Moroccan Thermal Construction Regulations (RTCM)?

2 Problem Statement

Energy renovation is the modification of different aspects of a building in order to improve its energy efficiency [14]. It is one of the main methods used to reduce energy consumption and greenhouse gas emissions in the construction sector. It is considered as one of the essential pillars of the 2050 transition towards sustainable buildings (International Energy Agency, 2013) [15].

In this paper, a literature review was conducted on the scientific database Google Scholar and Scopus for the period of 2018–2020 using combinations of keywords related to the subject of large-scale energy renovation/retrofit of buildings in morocco. Mainly RTCM, Energy retrofit, archetype, Energy simulation, GIS, Urban modelling, energy planning …

In the following paragraph, we present an overview of the most relevant research work that was carried out in Morocco:

In Ref [16] the authors used a single house in different climates as a typology for the energy performance analysis. They propose three scenarios, two of which are based on the RTCM. The results obtained show that the third scenario is the most favorable. It records the best indicators in terms of thermal performance, while the other two are more optimal for cold climates. In [17], the authors propose an energy simulation of a building with RTCM requirements in order to evaluate its impact on savings and energy bill. Their results show the effectiveness of RTCM and prove that its cost can be overcome in all climate zones and for some categories of buildings. In Ref. [18], the impact of thermal insulation on a typical Moroccan building and on its energy self-sufficiency was studied. TRNSYS was used to perform the simulation under a platform associating a hybrid system of two renewable energies (Wind and photovoltaic) to the thermal loads of the building. The results indicate that the impact of thermal isolation on self-sufficiency in all climates is very significant. For a different type of residence, the work in [19] presents a study of the energy efficiency of social residency buildings in Morocco. The objective being to compare active and passive solutions. The study was carried out in TRNSYS on a reference building in all six Moroccan climatic zones. The comparison shows that solar water heating solutions are more economical than thermally insulating the exterior building envelope from an energy point of view. For tertiary buildings, the authors of Ref [20] present a parametric study of thermal renovations of an administrative building in the region of Chefchaouen, Morocco. The authors performed a TRNSYS simulation of the multi-zones of the building envelope according to several different scenarios of occupation, insulation as well as integration of passive techniques. The results show that the optimal solution that follows RTCM regulations costs around MAD 391,31/m^2 (\$39,73/m^2), or 154 MAD 022,26 (\$15 640,60) excluding VAT for the entire building of 393,6 m^2. In Ref [21], the authors studied the impact of several energy efficiency measures (thermal insulation, building orientation, floor level, ventilation etc.) on energy performance and thermal comfort in an apartment located in Marrakesh using TRNSYS. The results show that a correct dimensioning of the thermal insulation of the walls ensures the prevention of summer overheating and consequently an optimal thermal comfort level. On the other hand, an oversized thermal insulation of the walls implies a rate of 18% for all climates of the thermal load during the summer overheating. Ref. [22] studies multiple thermal insulation scenarios using the BINAYATE software for a residential building located in Zaouiat Sidi Abdeslam, in order to choose the best scenario of insulation. They conclude from their results that glass wool leads to the best outcome, with 63% energy reduction and a payback period of 4.3 years. In Ref [23], the authors analyze the influence of the building envelope parameters on heating and air-conditioning demand using thermal simulations in TRNSYS for a building in the northern city of Tetouan. They proposed an improvement of its energy efficiency using passive techniques. Ref [24] studies a combination of building envelope parameters that allow for the lowest energy demand in heating and ventilation. In this case, DesignBuilder is the software that's been used on a typical building in the region of Casablanca. Results show a significant decrease in demand by up to 30% of the total consumption and that the parameters of thermal insulation have the greatest influence on the building's performance. In Ref [25], the authors performed a thermal study and a comparative analysis between a conventional house and two small low-energy consumption buildings in the climate of the town of Ben Guerir using DesignBuilder. The results show that combining appropriate construction materials with passive strategies allows for the reduction of thermal loads of houses. Ref [26] studies the thermal performance of two buildings located in two different climates (namely Midelt and Marrakech) constructed according to bioclimatic principles such as orientation and compactness. The authors then analyzed their architecture, relationship with the climate, use, thermal comfort, as well as performance related to RTCM. In Ref. [27], the authors carried out a study to evaluate the parameters of the envelope (orientation and insulation) on energy consumption. The TRNSYS simulation of a reference building in different climate zones in Morocco shows that the orientation plays a significant role in reducing the total load and affects the efficiency of insulation.

The literature review has shown that the majority of works related to energy retrofit in Morocco are concerned with the individual building level, and that there is a significant lack of studies evaluating energy retrofit at a larger scale (i.e. District, City) based on the RTCM regulations. We also note that there are three main software suites that were used: TRNSYS [28], BINAYATE [29] and DESIGN BUILDER [30]. The energy efficiency measures that were most popular are thermal insulation [18, 20, 22, 23] of the building envelope, orientation, and outdoor shading [26, 27].

In other side, urban energy retrofitting strategies can be categorized by the energy modelling approach that is used [13, 14, 31] (into top-down or bottom-up methods), by the nature of the models (physical-statistical) into white, gray or black-box models. This is due to the fact that energy modeling is an essential tool that is shared by most energy-related studies for renovation, building integration, energy planning of new districts/neighborhoods, or for comparative studies [32].

The main contribution of this paper is to propose a methodological framework for the evaluation of energy retrofit strategies not only at the single building scale, but also on the urban scale (district, city). The method is based on the extraction of archetypes from the urban environment, performing a simple energy simulation using the BINAYATE software which was designed to meet RTCM standards, as well as using the GIS tool to extrapolate the results on the whole studied area. On the other hand, the model allows for the evaluation of the impact and energy gains obtained from reducing the heating and air-conditioning loads in a future large-scale, RTCM-compliant energy retrofit strategy.

3 Problem Approach

The proposed methodological framework is based on a bottom-up approach in a multi-scale GIS environment. It combines physical and statistical methods to split up the building stock market into different archetypes.

In figure Fig. 1, the methodology that is used comprises 4 main phases, each phase is divided into a number of steps to be performed. The specifics of each phase and step are detailed in the following subsections.

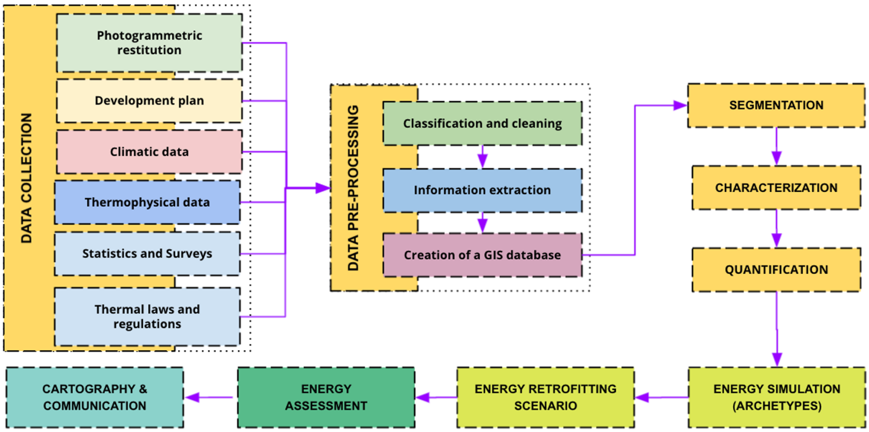


Fig. 1. Workflow

3.1 Data and Geometric Modeling

Data Collection: This phase consists mainly of gathering data of various types (geometric or non-geometric) about the building stock from various sources.

This data will then be stored in a geographic database that is supported by a GIS that simplifies the bottom-up mapping of the results at the end of the process.

The GIS tool is very useful at this stage, it provides a framework for data acquisition and sorting onto overlaying layers, thereby simplifying the management and analysis of energy renovation in a specific geographical location at the city-scale.

Data Preprocessing: This step allows one to filter, classify, and improve the quality of the collected data by detecting and filtering outliers and anomalies. Similarly, it allows one to extract the implicit information that is behind the raw data of the building stock, and to transform this data into a more comprehensible format. For example, extracting the morphological parameters from the urban form from photogrammetric restitution and city layout plans.

Segmentation of the Building Stock: The goal of this step is to group the buildings into the same class when they are as similar as possible using the clustering method.

The variables of the building stock are used to classify the buildings according to their similarities into groups of archetypes. These archetypes summarize similar buildings into a single representative building [33], and they collectively represent the characteristics of the whole building stock.

To ensure that no particular weight is given to any specific characteristic over another, and given that the clusters are calculated in terms of the distances between the data points, the variables with the highest values dominate the variables with lower ones. In order to solve this problem, a normalization and standardization step is necessary [34] to equalize the scale of values. The normalization is performed by weighing the differences between orders of magnitude in the values of the urban database [35].

Characterization: In this phase, we define the construction materials and the thermodynamic parameters of the parts constituting the envelopes of buildings. Existing work in literature relating to the Moroccan context is used, along with the materials' library of building energy simulation software "BINAYATE" [29], that is curated by the Moroccan Agency for Energy Efficiency (AMEE).

Next, we define the U-values of each component of the envelopes (roofs, facades, windows, ground floors etc.) from the thermal conductivities of each construction material.

Quantification: The goal of this phase is to analyze the distribution of the structural and dimensional characteristics of the archetypes (reference buildings) throughout the town [36].

The data in the GIS database is accessed and processed using queries. The spatial analysis allows us to classify each building according to its corresponding archetype. This will simplify the process of extrapolating the results of the energy simulation over all the buildings of the town.

3.2 Energy Simulations

Energy simulations at the urban scale are performed through the simulation of the aforementioned representative archetypes of the building stock. This considerably reduces the modelling and simulation time required for each individual building. Simulating a few dozen archetypes instead of thousands of buildings seems like a good cost-saving solution.

A number of simulation software suites can be used for the evaluation of the energy performance of buildings. In fact, in order to adapt as much as possible to the Moroccan context of the study, these energy simulations of the archetypes are performed using the AMEE developed software BINAYATE. It's a diagnostics tool for buildings to control their performance and assess their compliance with the RTCM. Furthermore, it can be used to calculate the annual energy needs of buildings according to their location, insulation envelope and other characteristics.

The BINAYATE software consists of three applications:

- BINAYATE 3D uses the BIM (Building Information Modeling) tool allowing the 3D modelling of the building's envelope elements.

- BINAYATE Performantielle calculates the annual energy requirements for heating and air-conditioning according to the climatic zone and the nature of the building (residential or tertiary). The calculations meet the Moroccan norms NM EN 15265: Performances thermiques des bâtiments - Calcul des besoins d'énergie pour le chauffage et le refroidissement des locaux - Critères généraux et procédures de validation; NM EN 12831: Systèmes de chauffage dans les bâtiments - Méthode de calcul des déperditions calorifiques de base; et ANSI/ASHRAE/ACCA Standard 183–2007 Peak Cooling and Heating Load Calculations in Buildings Except Low-rise Residential Buildings [37]
- BINAYATE Prescriptive: evaluates the technical specification given for each building and each climate zone. It does so in the form of maximum values for the coefficients of surface heat transmission of the various elements of the envelope as well as the solar factor.

BINAYATE is based on RTCM which is itself based on the parametric study that was performed in 2014 [38]. In this study, the authors carried out a sensitivity analysis of the influence of different envelope parameters of a building (residential and tertiary) on its heating and air-conditioning requirements.

Other norms are also used for the development of BINAYATE, namely (Table 1):

Table 1. Interior conditions of BINAYATE taken during energy simulations based on [38]

Interior condition	Week		Weekend	
Horaires	7:30–17:00	17:00–7:30	7:30–17:00	17:00–7:30
Type of activity	Residential			
Occupancy (person)	2	5	5	5
Ventilation rateincluding infiltration	30 m^3/h per person			
Interior gains sum up	2500 kwh/year per dwelling			
External shading (by summer) from 15 May to 15 September	50%	-	50%	-
Set point temperature heating	20 °C			
Set point temperature cooling	24 °C			

Other norms are also used for the development of BINAYATE, namely:

- NM ISO 13786: Thermal performance of building components—Dynamic thermal characteristics—Calculation methods.
- NM ISO 6946: Building components and building elements—Thermal resistance and thermal transmittance—Calculation methods;
- NM ISO 13789: Thermal performance of buildings—Transmission and ventilation heat transfer coefficients—Calculation method;
- NM ISO 13370: Thermal performance of buildings—Heat transfer via the ground—Calculation methods; [39]

3.3 Assessment of the Energy Gain

The objective of this step is to evaluate the impact of the heating and cooling needs of the building on its energy performance. The energy savings gained by implementing the standard renovation scenario (RTCM) on an urban scale are also estimated in this step.

The estimated energy gain can be calculated by the following ratio:

$$\text{Gain}\ (\%) = (\text{BE\_exist} - \text{BE\_rtcm})/\text{BE\_exist} \tag{1}$$

- ***Gain:*** *Estimated energy gain*
- ***BE_exist:*** *Current state energy needs*
- ***BE_rtcm:*** *Energy needs after the RTCM-compliant renovation scenario*

The estimated energy gain can be used as a performance indicator when making large-scale energy renovation projects. It allows one to recognize the most suitable energy efficiency measures and evaluate different large-scale retrofit strategies for implementation on a given building stock environment by ranking them according to the energy savings achieved with the highest performance scenarios.

3.4 Mapping and Outreach

Mapping the standard energy renovation scenarios of all the building stock can represent, on the one hand, a valuable tool for stakeholders and decision makers in energy planning studies, allowing to identify geographical priority zones for renovation, to target specific types of buildings, to calculate the surfaces of envelope areas, to estimate the energetic and economic gains of each scenario, to spatially analyze the impact of retrofit scenarios, and to know the initial and final states of each building, district or urban zone (Fig. 2).

Fig. 2. Mapping and outreach

4 Study Area

To demonstrate the applicability of the proposed methodological framework and its implementation, a study on the residential building stock domain of the town of M'diq will be presented in the following section.

The town of M'diq (35.6853 North, –5.32744 East), located in Northern Morocco, has a mountainous terrain, rugged topography and a Mediterranean climate.

In terms of demography, the town has undergone significant demographic growth, with 56,227 inhabitants in 2014, an increase of 19,631 since 2004, which corresponds to an annual growth rate of 5.3%, ranking it among the highest in the country. Furthermore, the average household size is around 4.1 (Fig. 3).

Fig. 3. Geographical location of the study zone

In terms of space, the city has a fragmented urban morphology. This is due, on one hand, to the rugged terrain itself (with slopes greater than 15°), and to poorly structured peripheral urbanization with ill-defined urban margins, on the other. The macro-form of the town is characterized by different homogeneous zones: The coast line, the seaport, the Cabo Negro forest, the mountain front, and the residential areas (Fig. 4).

In terms of age, the building stock of M'diq is relatively old, assuming an amortization period of 50 years. According to RGPH, around 39.7% of residential buildings are aged between 20 and 50 years, 35% between 10 and 20 years, 22.4% below 10 years and 2.8% are over 50 years old. It is clear that the vast majority of buildings were built before the implementation of the RTCM.

This methodological approach has been applied to the modern Moroccan dwelling, seeing as it constitutes the dominant building type in the Moroccan building stock. The case study was performed in the "Bouzaghlal" district towards the north of "M'diq", a town classified in the second climate zone "Z2" (Fig. 5).

The "Bouzaghlal" district is a recent neighborhood located in the outskirts of the town and covers a total area of 45ha. 10,73ha of which are occupied by 1220 residential buildings, most of which are modern Moroccan apartment-buildings. The density of these varies quite significantly from very dense regions to sparse, but growing ones which will also become more densely populated if current trends continue.

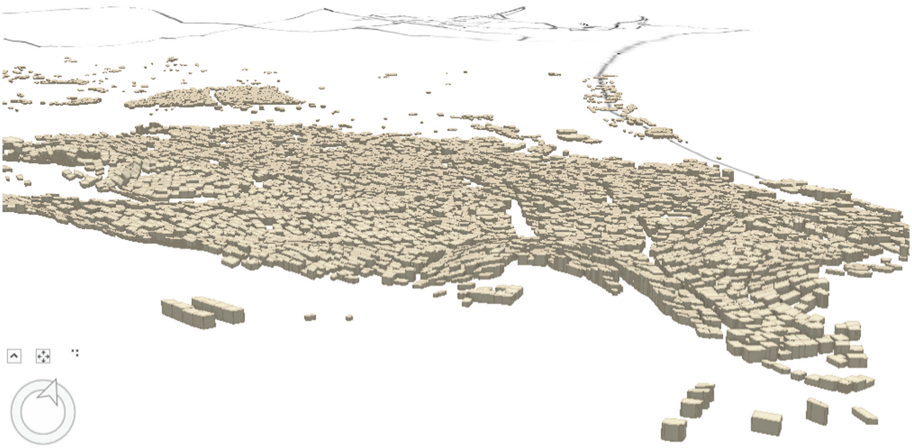


Fig. 4. 3D scene of M'diq city

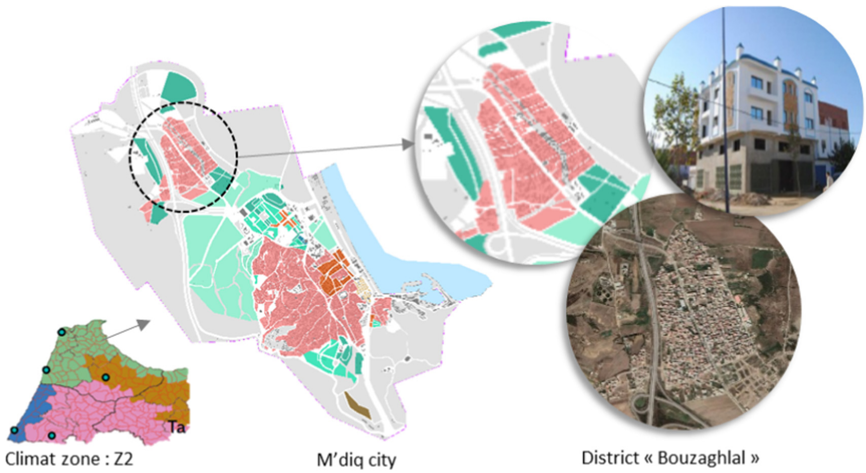


Fig. 5. Study area

5 Results and Discussion

Urban Geodatabase: The first phase of our methodology has allowed us to extract and sort the available data on the buildings of the district. The variables acquired in this phase will be used in the next phase where we divide the set of buildings into archetypical groups.

Results of the Segmentation Phase: Using the urban geographical database, we consider that buildings with similar data points are likely to have similar characteristics, construction techniques, insulating envelope quality and general geometry [35]. The proposed method for the segmentation of the building stock is broken into two steps:

– A "macro-segmentation" step based on the general segmentation criteria such as: Climate zone, type, construction date.
– A "micro-segmentation" step based on morphological factors and contiguity for more fine-grained results.

In our case study, all the buildings belong to the same climate zone "Z2", which is characterized by a Mediterranean climate. A comparison of historical imagery from Google Earth indicates that the majority of buildings are recent constructions between 2003 and 2021. Moreover, the dominant building type is, as expected, the modern Moroccan dwelling. This allows us to make the assumption that "Bouzaghlal" district is fairly homogeneous in terms of climate, age and building types (Fig. 6).

2003 2021

Fig. 6. Historical satellite imagery of the concerned district in the case study (2003 and 2021)

For the micro-segmentation of the district, the clustering technique used consists of classifying buildings in the same group when they're as similar as possible [40]. The most well-known methods are Hierarchical Clustering, k-means and k-medoids, with the k-means algorithm being the most widely used. The k-means method groups buildings using the displacement of instances between clusters, starting from an initial partitioning, in such a way that within-cluster variations are minimized. This is achieved by minimizing the sum of euclidean distances between the points and their centroids [40, 41]. The results of clustering are summarized in the following Table 2:

Table 2. Results of the clustering of the buildings of the "Bouzaghlal" district

Cluster	Building area (m^2)	Building height (m)	% Adjacency	Building orientation (°)
C1	96.35	8.76	29.65	−24.24
C2	100.55	8.27	16.90	64.38
C3	85.96	9.51	54.27	54.53
C4	194.71	9.02	19.78	25.25

Each aggregate and centroid value from the clustering represents the characteristics of an individual archetypical building.

Archetype Characterization: In morocco, floor construction techniques using full slabs has been mostly replaced by floor hourdis since the 1990s. For walls, current construction techniques generally consist of double walls [42] (Table 3).

Table 3. Thermophysical properties of the constituent elements of the envelope elements for the building type: modern Moroccan house based on [18, 23, 43]

Building envelope	Materials	Thickness (cm)	Density kg/m^3	Conductivity W/m k	Specific heat J/kg k
Facades	Plaster	1	1350	0.560	1000
	Cement	1.5	2500	1.8	1000
	Brick	10	918	0.241	741
	Air layer	10	$R = 0.18\ m^2\ K/W$		
	Brick	7	938	0.247	741
	Cement	1.5	2500	1.8	1000
	Plaster	1	1350	0.560	1000
Side wall (adjacent buildings)	Plaster	1	1350	0.560	1000
	Cement	1.5	2500	1.8	1000
	Brick	10	918	0.241	741
	Brick	10	918	0.241	741
	Cement	1.5	2500	1.8	1000
	Plaster	1	1350	0.560	1000
Exterior wall	Plaster	1	1350	0.560	1000
	Cement	1.5	2500	1.8	1000
	Brick	10	918	0.241	741
	Cement	1.5	2500	1.8	1000
Interior wall	Plaster	1	1350	0.560	1000
	Cement	1.5	2500	1.8	1000
	Brick	10	918	0.241	741
	Cement	1.5	2500	1.8	1000
	Plaster	1	1350	0.560	1000
Roof	Tiles	2	2300	1.3	840
	Screed	10	2500	1.8	1000
	Hourdis	20	1456.7	1.176	1000
	Cement	1.5	2500	1.8	1000
	Plaster	1	1350	0.560	1000

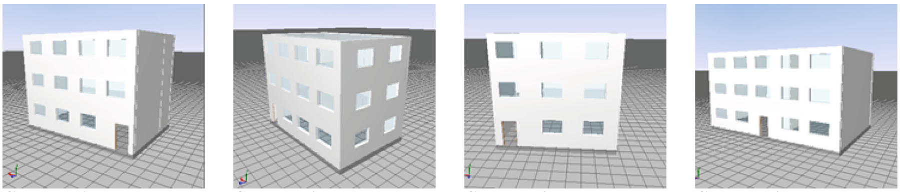
(*continued*)

Table 3. (*continued*)

Building envelope	Materials	Thickness (cm)	Density kg/m^3	Conductivity W/m k	Specific heat J/kg k
Floor	Tiles	2	2300	1.3	840
	Screed	10	2500	1.8	1000
	Concrete	20	1456.7	1.176	1000
	Sand and gravel	15	1950	2	1000
Windows	Single glazing	U = 4.88 W/m^{2}k, Solar factor: 0.52			

The U-values of each component of the envelope (roofing, facade, windows, floors) are defined using these thermophysical properties which are based on the construction materials. They are assumed to be similar for every building given that construction techniques and materials have not significantly changed since 2003 when the district was first created. It should also be noted that no buildings were subject to energy retrofitting in the district.

3D Modeling: 3D modeling of the previously discussed building archetypes is necessary before an energy simulation can be performed, and it is done based on architectural designs. The results of the 3D modeling step are shown below for each building archetype (Fig. 7):



Cluster B1
-Area : 96.35 m
-Height : 8.76 m
-% Adjacency : 29.65%
Orientation :114°

Cluster B2
-Area : 100.55 m
-Height : 8.27 m
-% Adjacency: 16.90%
-Orientation :25.62°

Cluster B3
-Area : 85.96 m
-Height : 9.51 m
-% Adjacency : 54.27%
-Orientation :35.47°

Cluster B4
-Area : 194.71 m
-Height : 9.02 m
-% Adjacency : 19.78%
-Orientation :64.75°

Fig. 7. 3D models of the building archetypes

Results of the Energy Simulation: The previously 3D-modeled archetypes are used as inputs for the energy simulation in the BINAYATE software. Below are the heating and air-conditioning needs of each archetype building (Table 4):

Table 4. Simulation results for the archetype buildings

Archetype	Conditioned floor area m^2	Heating		Cooling		Total	
		kWh/y	kWh/(m^2.y)	kWh/y	kWh/(m^2.y)	kWh/y	kWh/(m^2.y)
C1	248.06	14179.82	57.16	9499.70	38.30	23679.52	95.46
C2	233.27	13958.75	59.84	10598.08	45.43	24556.84	105.27
C3	207.82	11834.67	56.95	7855.88	37.80	19690.55	94.75
C4	516.38	25901.34	50.16	19759.83	38.27	45661.17	88.43

These archetypes are generalized using the GIS over the enter district to calculate its yearly energy balance.

Quantification: The GIS operations, specifically the queries and spatial joint, allow us to classify each building in this zone according to its corresponding archetype, simplifying spatial identification and data extrapolation. As a result, the computation of the total energy requirements of the district becomes a simple addition operation.

In this step, each building is labelled by its matching archetype as indicated in the following map.

Fig. 8. Distribution of buildings in the "Bouzaghlal" district by archetypes

To estimate the energy requirements for the whole district, we calculate for each building the net conditioned floor surface which does not consider hallways, stairways, cupboards, interior wall widths. This is because information related to cupboards or hallways is difficult to obtain and collect. We only estimated the surface occupied by stairways and exterior walls, and that is, therefore, the only surface that is subtracted from the total floor area.

We suppose that the wall thickness is 0.25 m and that the average stairway surface area is (2,60 m * 2.40 m). The net heated/air-conditioned floor surface is estimated by the following equation (Fig. 8):

$$\text{SP\_NET} = \text{SP\_gross} - \text{S\_stairs} \times \text{N} - (\text{P\_}\textit{buil} \times 0.25 \times \text{N}) \quad (2)$$

- ***SP_NET:*** *net heated/air-conditioned floor surface of building.*
- ***SP_gross:*** *Gross Surface area of the building's floors*
- ***S_stairs:*** *Average stairway surface (2,60 m × 2.40 = 6,24* m^2*)*
- ***P_buil:*** *Building Perimeter*

- ***N****: Number of floors*
- ***0.25****: Thickness of the exterior walls(m)*

Afterwards, the total yearly energy requirements for thermal comfort in each building in the district is calculated with the following equation (Fig. 9):

$$\text{BE (Bi)} = \text{SP\_NET(Bi)} \times \text{BE (Ci)} \tag{3}$$

- ***BE (Bi):*** *Yearly energy requirements for thermal comfort in a building of archetype Ci.*
- ***BE (Ci):*** *Yearly energy requirements per surface (m^2) for thermal comfort in a building of archetype Ci.*
- ***SP_NET:*** *Net heated/air-conditioned floor surface of building Bi* (Table 5).

Table 5. Annual energy balance for heating and cooling the “Bouzaghlal” district

Heating energy needs (MWh/year)	Cooling energy needs (MWh/year)	Total energy needs (MWh/year)
14881,08	10527,58	25408,66

Fig. 9. Spatial distribution of the calculated energy demand for the “Bouzaghlal” district

The results of the energy balance calculation show that the heating demand is higher than the cooling one for the “Bouzaghlal” district. This is due to the Mediterranean climate that is typically characterized by hot, dry summers and mild winters. This, in turn, means that savings can be made in heating more so than in cooling, which is also the case for the rest of the country, except in very hot climate zones.

Evaluation and Performances: In this section, we present the results of the evaluation that was performed on the impact of implementing the RTCM thermal regulations on heating/cooling requirements in the district.

According to the RTCM, the technical specifications of the thermal performance of residential buildings are mainly related to heating/air-conditioning requirements, which are capped at 46 kwh/m^2/year for zone Z2.

In a standard RTCM-compliant renovation scenario applied to the district in the future, the estimated energy savings can be calculated using the Eq. (1).

The total energy savings of each building and the energy that can be saved for the district is summarized in the following Table 6:

Table 6. Energy requirements and total energy savings for an RTCM-compliant renovation scenario for the "Bouzaghlal" district.

Current energy needs (MWh/year)	Energy needs after the RTCM-compliant renovation scenario (MWh/year)	Estimated energy savings (MWh/year)	Gain (%)
25408,66	12089,19	13319,46	52,72

Implementing the RTCM through an energy renovation scenario at the scale of "Bouzaghlal" district leads to a significant reduction in heating and air conditioning requirements, with total annual savings of 52.72% relative to the current situation. This result reflects the rate of energy savings that can be achieved in an urban environment.

Mapping and Outreach: The maps that we obtained can be included in the municipal geoportal [44], in solar cadastres [45], or for outreach and communication of the results before and after the renovation scenario to citizens. This would help them with decision-making and allow them to study the feasibility of their renovation projects (Fig. 10).

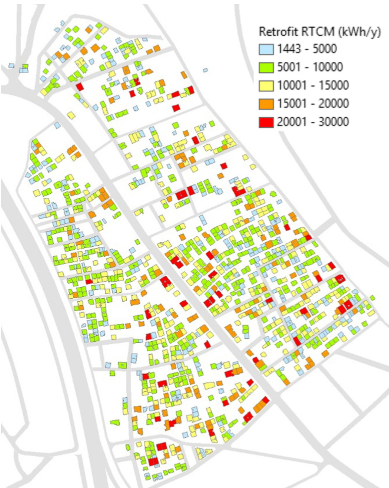


Fig. 10. Distribution of annual energy needs in the case of a standard renovation RTCM

6 Conclusion and Perspectives

During the last decade, developed countries made significant efforts to improve energy efficiency and retrofit of their building stock. This is not the case, however, for developing countries, including Morocco, due to financial difficulties and lack of skilled labor. Hence, public authorities need simple approaches, operational methods and flexible tools to simplify the identification and efficient evaluation of the scope of energy efficiency. This would help with and accelerate the mastery of the process of strategic energy renovation planning.

In this paper, we proposed a methodological framework to support decision-making processes in terms of energy planning at the urban scale by evaluating the impact of energy renovation strategies of heating and air-conditioning demand. Similarly, the model allows the estimation of the energy savings that can be achieved in an RTCM based energy renovation scenario.

The proposed methodological framework is based on a bottom-up approach in a multi-scale GIS environment. It combines physical and statistical methods to divide the set of buildings into different archetypes that represent the main physical and geometrical characteristics of the studied area. The archetypes are subsequently analyzed and their performance assessed by an energy simulation using the BINAYATE software in order to estimate the heating and air-conditioning demand before and after the implementation of an RTCM based energy retrofit scenario. The results of the simulation are then generalized and extrapolated on the entire set of buildings using the GIS tool that gives the possibility to aggregate them at different scales. Thus, we can calculate the estimated energy savings that are used as a performance indicator for the evaluation and prioritization of different renovation strategies and energy efficiency measures that are to be applied in a given building stock domain.

This methodological framework was applied to a typical modern Moroccan residential building. The case study was carried out in the «Bouzaghlal» district in the north of M'diq, which is a town in the Z2 climate zone. The implementation of an RTCM-based energy retrofit scenario at the district scale has achieved significant energy savings of up to 52.72%. This mapping of different energy renovation scenarios for the entire urban environment will present, on one hand, a supportive decision-making tool for energy planning studies, and a tool to encourage citizens to join and adhere to the energy renovation process on the other.

In this work, this method was considered for the typical building of a modern Moroccan apartment-building, which is very widespread and is the dominant type of building in the country. However, it should be noted that this framework can be used for other types of buildings.

Future research will pertain to the application of the study to all the districts and neighborhoods of the M'diq town with an energetic analysis of other building typologies in local housing.

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