Integrated Management Tool for the Promotion of Energy Renovation on an Urban Scale

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Abstract- Going beyond the building scale, energy renovation at the urban scale seems very complex and costly, requiring enormous time and effort. In this research, we will expand the reflection to the urban scale, since it is clear that the future environmental challenges will be solved at multiple spatial scales (building, block, district, city, region). To properly conduct energy renovation projects on a large scale, calculating energy needs is a vital starting point for diagnosing the existing state, comparing the energy scenarios, and simulating the future state of the building stock. This article seeks to present a GIS tool called "OGI-GeoRen" that is based on the spatialization of the simplified method of the NM ISO 13790 standard in a GIS cartographic environment. The tool allows the simulation of many buildings at the same time as well as the spatial evaluation of heating and cooling energy needs at the urban scale with reasonable accuracy and computation time. To demonstrate its feasibility and robustness, a case study was held in a district of 1219 buildings in a Moroccan context. The uncertainty analysis through the calculation of the indexes of the standard ASHRAE 14 has returned acceptable values of CV (RMSE) ≤ ± 4% and MBE ≤ ± 2.65%; this shows that the "OGI-GeoRen" tool has a satisfactory level of reliability for the prediction of buildings energy needs in comparison to the software BINAYATE, which could be very useful for urban energy efficiency projects at multiple spatial scales, such as urban energy planning for eco-districts and eco-cities.

Keywords: Archetypes, Modeling, Simulation, Energy retrofit, GIS, Urban scale, RTCM, ISO 13790.

1 Introduction

In recent years, developed countries have multiplied efforts to ensure the energy transition of cities [1] [2], particularly through the establishment of energy renovation projects [3]–[6] and green construction at the urban scale. As an example, the European program "Green Deal" aims at making Europe a climate-neutral continent as of 2050 [7]–[9]. Nonetheless, the situation of developing countries appears to be very limited due to numerous challenges such as high initial costs, uncertainty about financial profit [5], a lack of expertise (techniques, methods, and approaches relevant to the context), and the operation's size (district, city, region).

To minimize the cost of such large-scale energy renovation and identify the most profitable energy efficiency measures, specific, multi-scale feasibility analyses are essential, in addition to assessing the generalized energy savings resulting from the various energy retrofit options chosen [10] that were chosen before the implementation and exploitation phases. This will ensure the anticipation of possible adaptations and modifications. This could only be realized through simulations and optimizations of energetic and financial profits on a large scale. Consequently, it is essential to have a tool that will estimate and evaluate the energy needs on a large scale for such urban energy projects. The literature review related to the Moroccan context reveals a considerable deficiency for such tools concerning other existing tools that are only designed for building scale, notably the BINAYATE software program [11][12][13][14] platform that is considered the most used thermal software program in the Moroccan context.

The NM ISO 13790 [15] standard is officially the adopted thermal model by the Moroccan authorities for the diagnosis and the calculation of compliance of the new constructions to the obligations exacted by the thermal regulation (RTCM), it represents a variant of ISO 13790 [16] international standard (Energy performance of buildings — Calculation of energy use for space heating and cooling), which was widely used in the literature on the scale of the building[17][18]. This standard is the basis of the development of the BINAYATE software program [11] that specializes in the thermal evaluation of individual buildings in Morocco, and it seeks to simplify the application of RCTM by the professionals and actors involved in the construction sector. The development of this software program was realized through an international collaboration with the United Nations development program (UNDP) and the Global Environment Facility (GEF). It was initiated by the national agency for the development of renewable energy and energy efficiency (ADEREE) and developed by the CYPE company [19].

The novelty of this article lies in proposing a coupling approach between the geographic information systems and the thermal model adopted by the Moroccan authorities to conform with the thermal regulation (RTCM) during future energy retrofit projects at the urban scale. This article attempts to highlight the standard NM ISO 13790 [15] at the urban scale (block, district, town) on which the software BINAYAT[11] is based. Furthermore, this spatialization of the standard in the GIS mapping environment allows for the multi-scale calculation of energy needs for heating and cooling for the total building stock.

In contrast to the commonly used approaches for the energy simulation of building stocks, notably the archetypical generalization that depends on the classification of buildings by their representative archetypes, the proposed tool in this research is based on a bottom-up building-by-building approach.

Given the goal of addressing the current lack of simulation tools for energy needs at the urban scale, the objective of this study is to develop a calculation tool for energy needs for heating and cooling to facilitate the process of executing future projects of energy renovation in Moroccan building stocks. The article presents the approaches that have been followed and the methodologies adopted to conduct and validate the tool.

"OGI-GeoRen" is a tool to overcome many of the problems associated with large-scale energy retrofit strategies. The tool will facilitate the management of data related to building stock (geometry, thermodynamic characteristics, climatic data, urban data, etc.) in the form of a geographical database composed of tables and interactive cartographic layers in a GIS consolidated environment. It also allows to:

- Fill the lack of tools for multi-scale estimation of the energy balances and gains in the Moroccan context.
- Dimensioning of multi-scale energy renovation strategies; in other words, the determination of surfaces of elements of the buildings to be renovated: roofs, walls, facades, glazing, and grounds; which facilitate the techno-economic study of the project.
- Facilitate the analysis of the sensibility of renovated elements and their impact on the global energy balance sheet of the building stock.

To analyze the validity and robustness of the proposed “OGI-GeoRen” tool, a case study was conducted in the neighborhood of Bouzaghlal in the town of M’diq which belongs to the climate zone Z2 in northern Morocco. The energy simulation results are validated by comparing them with a sample building simulated by the BINAYATE software program [11]. Also, the two principal uncertainty indexes of the ASHRAE 14 directive [20] were calculated for the validation of the tool

The document is structured as follows; section 2 focuses on the literature review and similar findings. In section 3, we detail on the methodology adopted in the development of this tool, the data used, and the adopted energetic model. In section 4, we develop the validation approach of the tool. In section 5, we present a case study of a district in the Moroccan context to test the applicability of the tool, in addition to discussing the results achieved to demonstrate the utility of the solution. In section 6, we evaluate the difference between the “OGI-GeoRen” tool and the Moroccan thermal simulation software program BINAYATE [11], and we conclude with conclusions and perspectives for future work.

2 Literature Review

According to the reviewed works, most existing building renovation studies are based on energy simulation and decision support tools and are often limited to the individual building level. In contrast, some studies have tackled energy renovation on a larger scale [21]. In addition, it was observed that these large-scale studies generally use a bottom-up approach rather than a top-down approach. Also, they employ data-driven and engineering methods (white box, gray box, or black box) [22] for modeling the building energy performance of building stocks [4], [23], [24]. For the simulations that are based on engineering methods, there are two processes that are followed to simulate the buildings: a simulation based on the generalization of archetypes on corresponding buildings or a targeted simulation building-by-building followed by aggregation of results. On the other hand, in the first phase, to manage spatial data and building stock attributes, many researchers have limited the use of GIS tools only to purely cartographic purposes, such as the geometric calculation of elements of the envelope (surface, volume, height, number of floors) and the visualization of data. Nowadays, GIS coupled with energy models has become a complete tool for modeling and energy simulation of buildings [24], [25], allowing calculation of energy needs and evaluation of investment returns of different interventions in the renovation building stock. The sections that follow focus on some urban-scale works completed using two approaches: the archetype approach and the building-by-building approach.

The archetype approach is based on the segmentation and classification of all the constructions in the building stock into reference buildings (archetypes) that are similar in physical characteristics (typology, age, climatic zone, U-values, modes, and materials of construction…) and geometry (architecture, spatial disposition, surface, height, volume, number of floors, compactness, internal structure….) [21], [26]–[28]. Subsequently, every archetype will be modeled and simulated, and then the results obtained for each one will be generalized throughout the same building class [4], [29][. Many articles have used this approach:

In a recent study, the authors of reference [21] evaluated the cost-effectiveness of the energy renovation of the Portuguese building stock. Based on the bottom-up approach, the authors calculated the energy needs and the investment costs required for the whole Portuguese building stock. For this goal, they used data from energy performance certificates, the different renovation measures existing in the market, and the requirements of nZEB. The results indicate that profound energy renovation requires an investment of 71.7 billion euros, and the thermal insulation of roofs is the most cost-effective measure. Similarly, to analyze the impact of energy efficiency measures on Italian building stock, the authors of reference [10] propose a bottom-up model called I-REM based on the archetypal approach. Their goal is to estimate the energy savings obtained for various scenarios of energy renovation. The results show that saving up to 38.4 TWh from now until 2030 is easily feasible. But, to save 7.8 TWh from now until 2030, it is necessary to apply some radical energy renovation measures. Also, they proposed an advanced scenario to achieve 100WTh from now until 2030, but that can be possible through the deployment of heat pumps. In another recent study [8], the authors developed a decision support system for the elaboration of optimal energy renovation strategies. Their method is based on clustering techniques to segment the building stock into groups of similar buildings. Furthermore, it runs the simulation Monte-Carlo to calculate the energy savings according to the chosen renovation measures. The case study was conducted on a database belonging to the region of Lombardy, Italy, which included over one million buildings.

Given the goal of evaluating the energy footprint and potential savings of railway buildings, the authors of the article [30] created a model based on a bottom-up approach using archetypes derived from different railway station data. They adopted a linear regression approach to building a simple surrogate model to use instead of detailed models. The results show that an overall primary energy savings of 26% can be achieved if highly efficient lighting systems are adopted, while the renovation of the envelope and the replacement of HVAC have less impact. Moreover, the primary energy savings are estimated to be 1.2% for improving the envelope and 14.3% for the renovation of HVAC systems.

In another study [9], the authors present an urban building energy model (UBEM) to support the “Renovation Wave” project, launched by the European Commission. The model was based on the archetype approach (Tabula) to generate the inputs needed to run the Urban Modeling Interface (UMI), which was to analyze the energy renovation measures at the neighborhood scale. In addition, the authors presented a case study comprising 9000 residential buildings in Dublin, Ireland. The results show that the most cost-effective way to achieve a 55% reduction in CO_2 emissions by 2030 is to focus on infiltration and insulation of walls and roofs.

With the same objective, the authors of the reference [29] present a web-based framework that aims to facilitate the generation of UBEMs to support the most efficient policies for decreasing carbon emissions. The developed tool uses the bottom-up archetypal approach, the dynamic simulation based on EnergyPlus, and the GIS environment to generate building geometry, the assignment of individual buildings to their corresponding archetypes, the calculation of energy needs, and the visualization of results at the urban scale. Next, the framework was tested in a case study in Evanston, U.S.A. The results show that adopting an energy retrofit scenario will allow the city to reduce energy use intensity by 23%, whereas a more profound scenario can allow for up to a 60% decrease, which is equal to a decrease of 13% and 59% of the annual carbon dioxide emissions, respectively.

The authors of references [31][32] suggest a methodological frame based on a bottom-up approach in a GIS multi-scale environment that uses physical approaches and statistics to segment the buildings into different archetypes. Subsequently, the results of thermal simulations were generated throughout the buildings in the district using the GIS tool. The case study conducted in a district located in northern Morocco has shown that the implementation of energy renovation at a large scale would allow the economization of energy by up to 52.72% in the case of respecting Moroccan thermal regulation. Furthermore, the authors of reference [33] have examined a building clustering approach to generate a range of personalized and adapted archetypes for the building stock. Considering the absence of buildings consumption data, they have evaluated whether the aggregation of the properties of the building would be an alternative to the aggregation of energy performance indicators. The results show that the aggregation of properties is a viable alternative with solid results.

Generally, studies of large-scale renovation are characterized by the lack of detailed data about the buildings in the study zone (physical, geometrical, structural, and interior properties) [33], [34]. The advantage of simulation through the archetypes approach is its capacity to fill the gaps in building data with a well-defined hypothesis for the evaluation of energy performance [3]. On the other hand, one of the major inconveniences of this approach is the reliability of the simulation results, whether for individual buildings or the final energy balance of the building stock [34], since it depends on the representativeness of the archetypes compared to the heterogeneity of the buildings in the study area. The more buildings are homogenous, the more reliable clustering and archetype generation will be; consequently, the results will be more accurate.

Contrary to the approach of simulation based on archetypes, the building-by-building approach simultaneously simulates the overall buildings individually, one after the other, which permits obtaining the energetic balance sheet for each building without interpolation or archetypal generalization. Consequently, the results could be gathered according to the scale needed thanks to these GIS tools [4].

Amongst the researchers that have adopted this approach: the authors of the reference [25] developed an urban energy modeling tool based on the bottom-up engineering approach, without defining the archetypes, supported by GIS, and its energy model is derived from the standard EN ISO 13790. Likewise, the authors proposed a workflow that permits the analysis of the efficiency and impact of the energy renovation on the performance of the building stock. The tool was used on three villages in Italy with 769 buildings. The results show global demand for primary energy during the heating season is 45.1 GWh. Also, the main losses are due to the transmission of heat through the envelope (about 84%). In the same way, the authors of the reference [35] present a methodology based on GIS without using the archetype's approach and the tools of simulation to analyze the saving potential of the heating demand of the building stock. The method was applied in the region of Aosta Valley in Italy (about 42000 buildings). The results show that this method slightly overestimates the total thermal demand of the building stock. Similarly, in the study [36], the authors have created an energetic simulation platform at the scale of the city based on the bottom-up model approach and electric analogy (resistance-capacity networks). The platform models the thermal behavior of buildings and provides the energy demand of urban zones. The authors have applied this model to two urban zones. The results show a good prediction of the energy demand of buildings with weak calculation resources. Other recent studies have developed the profitability of energy efficiency measures like the reference [37] where authors implement an integrated methodology that analyses and evaluates the measures of conservation and production of energy at many scales to optimize the planning of the renovation at the district level. They have developed a tool that simplifies the choice and classification by order of profitability of the most performing measures. The case study is applied to a group of 48 university buildings in Berlin.

The reliability of simulation results according to the building-by-building approach depends on the quality and availability of inputs, yet it is generally more precise than the archetypes approach, for the fact that simulations are realized at the micro-scale (building-by-building) without the abstraction that characterized the archetype's elaboration process. The main inconvenience of this approach is the massive quantity of data demanded to model and simulate a building stock because of its dimension [4], which makes it a costly approach at the level of collecting data and calculating resources.

In sum, the literature review shows the existence of different attempts at modeling and simulation of urban zones' energy needs that differ according to the context, objectives, inputs, simplification of models, and degree of precision facing the capacity of calculation. But till now, no reliable or generalizable solution has been realized due to so many challenges, including the scale of the urban zone and the availability of the building's detailed data [3]. From a methodological point of view, the different implemented solutions generally adopt a bottom-up approach according to aggregation by archetypes or a building-by-building aggregation that focuses on simplifications of physical models and inputs.

Additionally, reviewing existing work shows a considerable lack of tools for forecasting energy balances at the urban scale compared to the building scale. In the Moroccan context, no multiscale solution has been found up to the present moment which has tackled the problem of predicting energy requirements for heating and cooling at the urban scale of the Moroccan building stock, either in what concerns the construction of new districts or future energy renovations. As a result, this study attempts to bridge the gap by developing a geospatial GIS tool called "OGI-GeoRen", which is based on the spatialization of the NM ISO 13790 standard [15] in the GIS environment and aims to calculate the monthly energy balance at the urban scale (blocks, districts, cities). The tool was designed to provide stakeholders and public authorities with a solution for analysis and evaluation of the best thermal isolation measures of buildings for low-carbon urban projects, especially the new districts and future energy renovation strategies of existing buildings or projects of eco-districts and eco-cities.

3 Methodology

At the individual building scale, several building energy simulation programs are proposed by designers to analyze and optimize energy performance in the initial phase of the projects. For the determination of heating and cooling needs, the majority of these programs are based on three main methods, namely:

- Estimation from a database of buildings that have archetypical references already simulated or measured according to a range of adopted hypotheses, either from values taken from existing literature of similar climatic and energetic contexts of the building under investigation; consequently, the results are approximate.
- A detailed dynamic simulation is the most precise method, but it needs detailed building data. It is used by a variety of software, like TRNSYS [38], DesignBuilder [39], Energyplus [40];
- The simplified method is based on the seasonal calculation used by international standards (ISO 13790:2008 [16] [25], ISO 52016-1:2017 [41]) that are characterized by good precision.

The "OGI-GeoRen" tool is a sort of spatialization of the NM ISO 13790 standard [15] in a GIS environment. It is based on python scripts of spatial geoprocessing coded from the thermal equations of the standard. The tool allows the calculation of energy needs for heating and cooling by the building-by-building approach at the urban scale. Consequently, it will be very useful for energy renovation projects at urban scales, while avoiding not only the simulation of individual buildings, which necessitates a lot of time and effort but also provides an alternative to archetypical methods.

Figure 1 represents the workflow of the "OGI-GeoRen" tool; it is composed of five main phases: after a first preparatory phase of inputs, the tool is composed of a range of python scripts and spatial geoprocessing tools that allow the definition of geometrics and the orientation of building envelope elements; subsequently, they will be used in the calculation of the energetic balance sheet of the zone to be studied; and finally, the cartography of outputs. Details of the phases and steps will be described below:

3.1 Data Collection and Preparation of Inputs

Geometric modeling and energy simulation require careful consideration of the elements that compose the building envelopes [6], including the climatic data of the study area. Generally, the parameters needed for these main steps are urban data (building typology), geometric data (surfaces, heights, volumes...), and thermophysical data (U-value of walls/roofs/floors/glazing...) for all buildings. Due to the huge quantity of this data at this scale, a GIS database becomes a necessary tool to consolidate, structure, and store all the input data in spatial layers and attribute tables to facilitate their exploitation [42]. Data quality and availability should be checked, including verification of parameters, correction of data gaps, and elimination of outliers.

Data Collection:

The most important data sources to obtain in order to extract the necessary parameters that will be input into the "OGI-GeoRen" tool are:

- Photogrammetric restitution from aerial shots of the study area: this type of data is generally realized by the topographical and photogrammetric studies offices for the municipality and urban projects, as well as studies of urban and spatial planning.
- Urban planning documents allow the extraction of typologies and the maximum authorized heights of buildings.
- A map for climatic zone division and annual climatic data of the study zone issues meteorological stations.
- Thermodynamic values of the construction and isolation materials, notably the transmittance, specific heat, and bulk density, are including BINAYATE's software program library of materials.
- Field investigations are essential to fill the gaps in building stock data.
- The Thermal Regulation of Construction in Morocco (RTCM) is to know the maximum values required according to the climatic zones

To overcome the shortage of information concerning the thermo-physical properties of every element of the envelopes of buildings at the urban scale, a hypothesis is based on the idea that all the buildings of the same typology, built in the same period, and with similar technical materials without any thermal modification of envelopes are probably similar transmittances. Based on the comparison of the history of images on Google Earth [42], [43] for the study zone, we see that the period of construction is from 2003 to 2021. Similarly, the techniques of construction that were used in this period were relatively similar. They are generally constructed of double partitions for facades, with simple brick walls and cement for adjacent and external walls, and "hourdi" beams for floors. Table 1 below gathers the thermos-physical properties of the elements of the envelopes of the buildings adopted according to the supposed materials of construction at that period. The U values of the materials for the construction of roofs, facades, windows, and floors are taken from the BINAYATE [8] library. The accuracy of the "OGI-GeoRen" tool results depends largely on the availability and reliability of the data requested in the process.

Inputs Preparations:

The preparation of the main inputs is done from the sources of data cited below; they form the essential starting elements for the functioning of the "OGI-GeoRen" tool.

- The georeferenced footprint of buildings.
- The roadway of the study zone.
- The height, surface, and scope of every building in the study zone.
- The typology of residential buildings "Modern Moroccan House"
- The number of levels of buildings corresponds to the number of floors estimated from the heights of buildings made of the restitution with the hypothesis that the height of the floor is three meters.
- The nature of the ground floor depends on the use of the residents; commercial use for garages on the main roads and residential use on the secondary streets.
- The transmittance of building components (walls, roofs, glazing, grounds).
- The intensity of solar radiation according to its direction.
- The monthly external temperatures.
- The indoor temperature setpoints.
- The rate of external air replacement per hour.
- The internal heat gains

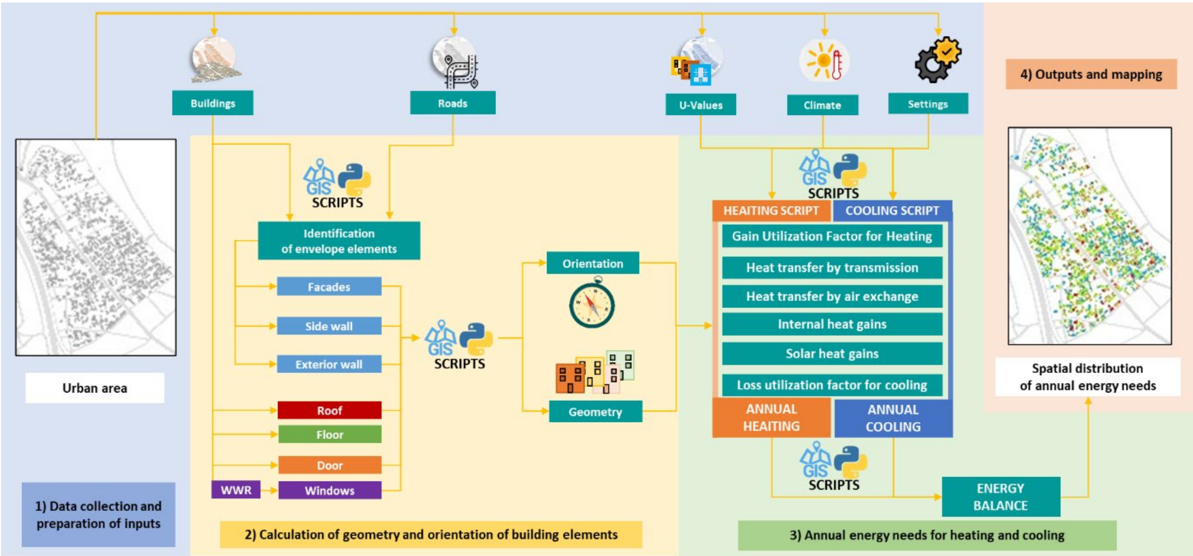


Fig. 1. Workflow

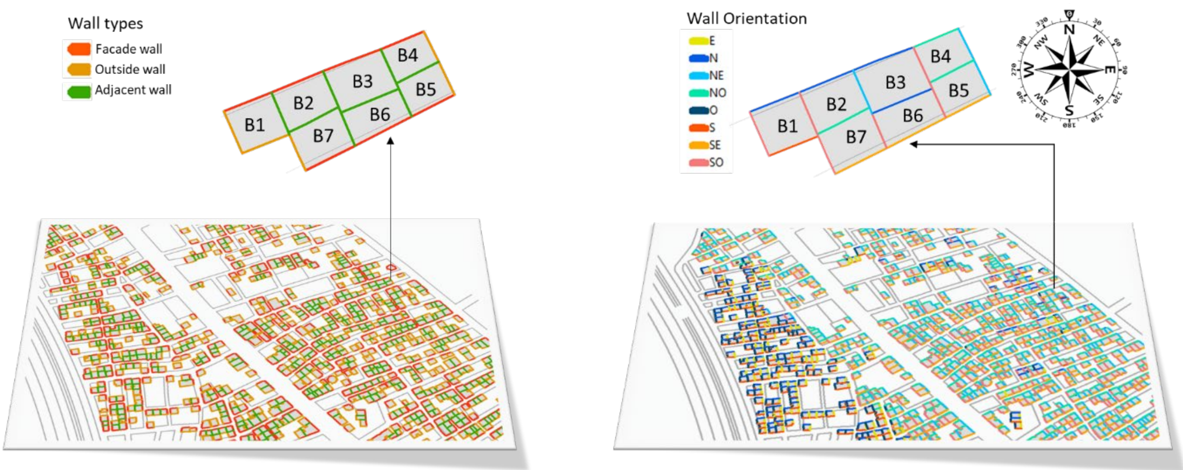


Fig 2. Types and orientations of buildings walls.

Table 1. Thermophysical properties of envelope elements for the building type "Modern Moroccan House" (Based on [31] [32])

Building envelope	Materials	Thickness (cm)	Density kg/m³	Conductivity W/m k	Specific heat J/kg k	U-Value W/m²k
Facades	A finish coat	1	1350	0.560	1000	0.91
	Cement	1.5	2500	1.8	1000	
	Brick	10	918	0.241	741	
	Air Layer	10	R=0.18 m² K /W			
	Brick	7	938	0.247	741	
	cement	1.5	2500	1.8	1000	
	A finish coat	1	1350	0.560	1000	
Sidewall (Adjacent buildings)	A finish coat	1	1350	0.560	1000	0.95
	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	
	A finish coat	1	1350	0.560	1000	
Exterior wall	A finish coat	1	1350	0.560	1000	1.57
	Cement	1.5	2500	1.8	1000	
	Brick	10	918	0.241	741	

	Cement	1.5	2500	1.8	1000	
	A finish coat	1	1350	0.560	1000	
Roof	Tiles	2	2300	1.3	840	for cooling: 2.24 for heating: 2.65
	Screed	3	2500	1.8	1000	
	Hourdis	20	1456.7	1.176	1000	
	Cement	1.5	2500	1.8	1000	
	A finish coat	1.5	1350	0.560	1000	
Floor	Tiles	2	2300	1.3	840	0.60
	Screed	3	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/m²k, Solar factor: 0.52, frame ratio: 0,45				
Door	Metal	U = 5.7 W/m²k, Absorption coefficient 0.6				

3.2 Geometry Calculation and Elements of Building Orientation

For the calculation of the energy needs of buildings, it is necessary to determine the received solar gains and the direct outward heat losses by the constructive elements of envelopes; in particular, the heat transfer by transmission via surfaces of the envelope and the air renewal by volume of the building. As a result, a Python script coupled with spatial GIS geometry tools is coded in the "OGI-GeoRen" tool to simplify the determination of the different elements of building envelope geometry. The developed tool allows for the automatic classification of the walls of the buildings according to their type (façade, external walls, and common walls) with the calculation of their surfaces and lengths (Figure 2). Similarly, it allows for the calculation of ground surfaces, roofs, glazing, and the volume of the building's envelope.

The orientation of walls and windows is a very important factor influencing the rate of solar gains from radiation received by the building envelope, which should be taken into consideration. For this purpose, the "OGI-GeoRen" tool calculates the orientation concerning the geographical north of every wall and window in the envelope of the building stock. Furthermore, it recovers the surface of the portions of walls and windows allocated according to the eight directions (N, NE, E, SE, S, SW, W, NW) as it is represented in Figure 2. The calculated surfaces based on the orientation will be exploited in the thermal equations of the NM ISO 13790 standard [15].

Generally, the roofs of the Moroccan building stock are flat, so we consider their orientation to be horizontal.

3.3 Annual Energy Needs for Heating and Cooling

Every building in the study zone is modelized as one delimited zone by the external walls, facades, windows, grounds, and roofs. The results for heating and cooling needs for this zone are the results of the total monthly energy balances of heat transfer and heat gains multiplied by the gain utilization factor for heating and by the loss utilization factor for cooling

To determine the energy needs at the building stock scale, our approach is based on the codification of thermodynamic equations of the monthly seasonal method of the NM ISO 13790 [15] standard into the environment (ArcGIS, ESRI) [44] via python scripts and GIS geoprocessing tools. This way, we exploit the surfaces and orientations of components of buildings envelopes calculated in the equations of internal and solar heat gains, in addition to the equations of loss via thermal transmission and ventilation. Below are the main equations of the method that were coded and applied to every building B(i).

Energy needs for heating:

$$Q_{H,nd\,(B_i)} = Q_{H,ht\,(B_i)} - \eta_{H,gn\,(B_i)} \times Q_{H,gn\,(B_i)} \qquad (1)$$

Where, for every building (B_i) of the study zone:

- $Q_{H,ht\,(B_i)}$: *Total Heat transfer*
- $Q_{H,gn\,(B_i)}$: *Total heat gains*
- $\eta_{H,gn\,(B_i)}$: *Gain Utilization Factor for Heating*

All the components of equation number (1) were adapted from NM ISO 13790 standard [15].

Energy needs for cooling:

$$Q_{C,nd\,(B_i)} = Q_{C,gn\,(B_i)} - \eta_{C,ls\,(B_i)} \times Q_{C,ht\,(B_i)} \qquad (2)$$

Where, for every building (B_i) of the study zone:

- $Q_{C,ht\,(B_i)}$: *Total Heat transfer*
- $Q_{C,gn\,(B_i)}$: *Total heat gains*
- $\eta_{C,ls\,(B_i)}$: *Loss utilization factor for cooling*

All the components of equation number (2) were adapted from NM ISO 13790 standard [15].

For heating, and after the definition and preprocessing of the input data, the "OGI-GeoRen" tool starts the calculation of the first component of equation number (1), notably the heat transfer, which is the total of transfers by transmission and by air renewal.

For every month, the transfers by the transmission of every building are calculated based on the difference between external temperatures and indoor setpoint temperatures multiplied by the coefficient of thermal transfer by a transmission that uses U-values and surfaces of building envelopes in its calculation. Similarly, the transfers by air renewal are calculated based on the difference between external temperatures and indoor setpoint temperatures multiplied by the coefficient of thermal transfer by air renewal, which is defined by the rate of air renewal and volumetric heat capacity. Subsequently, the tool calculates the second component of equation (1) that corresponds to the total heat gains, which is the sum of internal heat and solar heat received from solar radiation. After that, it calculates the third component of equation (1) for every building that corresponds to the gain utilization factor for heating.

Moreover, the entire components of equation (1) allow for the calculation of energy demand in heating for every building, and that's for every month of the heating period (January, February, March, April, May, November, and December).

For the calculation of energy needs for cooling, the OGI-GeoRen" tool repeats for every building in the study zone the same steps with the previously explained sequence in the paragraph above, and that's for the months of the cooling season (June, July, August, September, October).

Finally, the tool executes a spatial join to gather the entire monthly outputs for every building in one GIS layer; the energy needs are referred in kWh/y and they normalized by the surfaces of the building's floors (kWh/y/m²).

GIS tools allow the exploitation of obtained results in the form of interactive maps rich in information that could be published through geoportals for the public or professionals to encourage projects of energy renovation at the city scale [32] [45].

3.4 Outputs and Results

The generated results at the end of the execution of the "OGI-GeoRen" tool are in the form of superposed and stored spatial layers in the GIS geo-database, and they are composed of the following outputs:

- The layers of buildings' walls that contain the length and the orientation are classified by type of wall (facades, external walls, adjacent walls).
- The building layer contains the geometric and thermodynamic properties of each building envelope component in the building stock, length, surfaces, height, volumes, perimeters, and U-values.
- The layers of 12 months contain the details of simulations, including internal heat gains, solar gains, thermal transmittance, ventilation heat flows, heating and cooling energy needs for each construction in the building stock.
- The layer of annual energy needs (heating and cooling) for every construction in the building stock.

Figure 3 below represents an overview of the arborescence of the "OGI-GeoRen" tool, the inputs, the outputs, and the GIS environment of the solution.

4 Validation

4.1 Validation Approach

To address the issues related to uncertainty and accuracy of energy simulation tools, the most ideal validation is one based on the comparison of simulation results with actual building consumption measurements. However, at the urban scale, the validation step is challenging since the real measures of electricity needed for the heating and cooling of buildings are unavailable for the Moroccan building stock. The suggested solution is the validation of the "OGI-GeoRen" tool based on the obtained results of the simulation of buildings on the BINAYATE software program [11], for the fact that it is a referential software program for the application of RTCM and is largely accepted in the Moroccan context.

The deviations considered in this study are the underestimations or overestimations of energy needs in heating and cooling obtained by the "OGI-GeoRen" tool versus the simulated results obtained by the BINAYATE software program [11] in two cases: before and after thermal isolation.

4.2 Uncertainty Analysis

According to the literature [23][33][46][47], there are many methods to measure the uncertainty and analyze the rigor of the energetic models for individual buildings, notably the ASHRAE 14 directive [20].

Since the directive does not have a dedicated standard to evaluate the rigor of models at the urban scale, the adopted approach consists of comparing the obtained results of the energy simulation via the "OGI-GeoRen" tool of a district considered as a case study with a sample of 20 simulated individual buildings by the BINAYATE software program [11]. The buildings were chosen randomly from the study zone with different surfaces, heights, and numbers of facades. The two uncertainty indexes of ASHRAE 14 [20] were calculated for heating and cooling: 1) the Normalized Mean Bias Error (NMBE) and 2) the Coefficient of Variance of the Root Mean Square Error CV(RMSE), which were largely used in previous energetic studies. Down below are their formulations:

The NMBE (Normalized Mean Bias Error) is the normalized average of the total of the differences between the measured and simulated data of a sample space; it represents a good measurement of the global behavior of the model bias. Positive values mean that the model tends to underestimate results; on the contrary, a negative value implies an overestimation.

$$NMBE\ (\%) = \frac{1}{m} \times \frac{\sum_{i=1}^{N}(SB(i)-SG(i))}{N} \times 100 \qquad (3)$$

With:

- *$NMBE\ (\%)$: Normalized Mean Bias Error*
- *$SB(i)$: Energy needs simulated by BINAYATE for each building in the validation sample;*
- *$SG(i)$: Results simulated by the OGI-GeoRen" tool for each building in the validation sample;*
- *m: average of the values simulated by BINAYATE of the energetic needs of N building.*
- *N: buildings of validation sample size*

The main disadvantage of the NMBE index is the canceling effect that is produced when the two regression lines of the simulated and measured data are so close. In other words, it is when the model is calibrated or almost calibrated. To overcome this inconvenience, another uncertainty index is also necessary to overcome the canceling effect. From these indexes, the Coefficient of Variance of the Root Mean Square Error CV(RMSE) is written as follows:

$$CV\ RMSE\ (\%) = \frac{1}{m} \times \sqrt{\frac{\sum_{i=1}^{N}(SB(i)-SG(i))^2}{N}} \times 100 \quad (4)$$

With:

- $CV\ RMSE$ (%) *: Coefficient of Variance of the Root Mean Square Error*
- $SB(i)$ *: Energy needs simulated by BINAYATE for each building in the validation sample;*
- $SG(i)$ *: Results simulated by the OGI-GeoRen" tool for each building in the validation sample;*
- *m: average of the values simulated by BINAYATE of the energetic needs of N building.*
- *N: buildings of validation sample size*

The CV(RMSE), as we can see, is a normalization of the average squared error RMSE by the average value of the dependent variable. It gives an objective representation of the global difference of the model and shows to what extent the simulated values could be close to the real measures. According to the measured data's frequency (monthly or hourly), the main validation criteria of energetic simulation models vary. For the ASHRAE 14 [20] directive, CV (RMSE), and NMBE indexes are generally considered acceptable if they respond to the following thresholds:

- For a monthly frequency (12 months/y):
  → CV(RMSE) ≤ 15% and NMBE ≤ ± 5%
- For an hourly frequency (8760h/y):
  → CV(RMSE) ≤ 30% and NMBE ≤ ± 10%

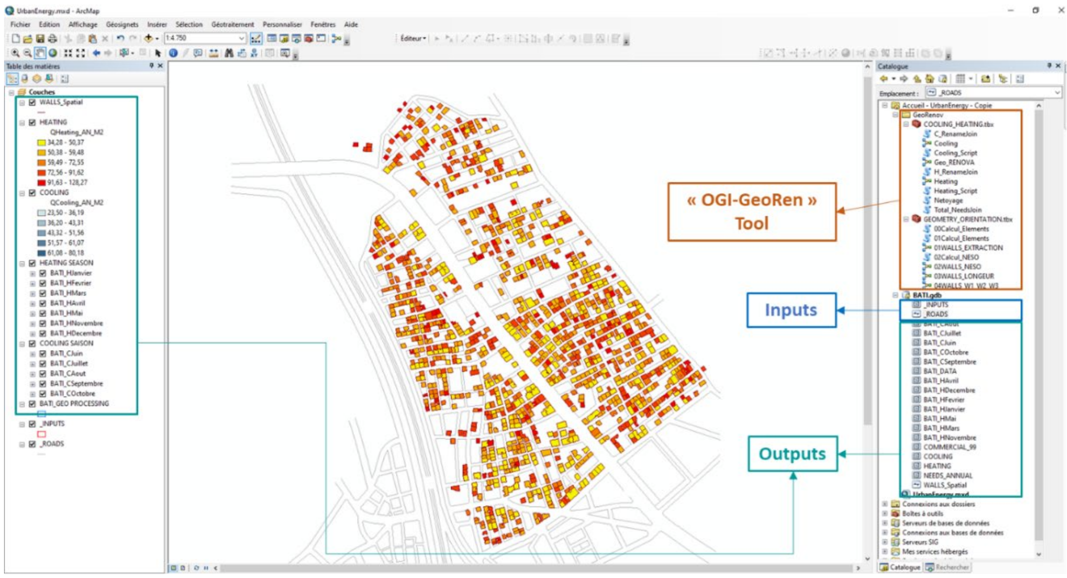


Fig 3. Inputs, outputs, and OGI-GeoRen" tool implemented in the GIS environment (ArcGis)

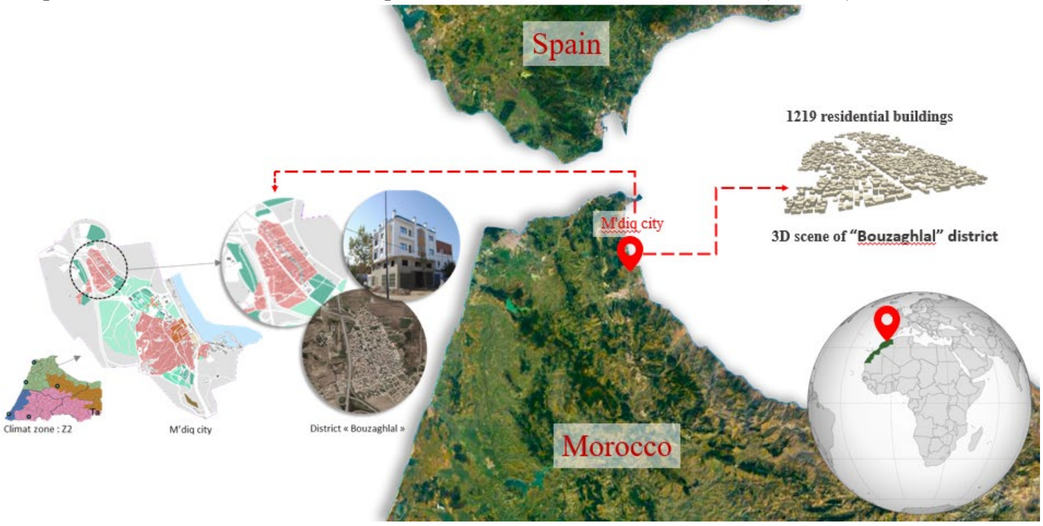


Fig 4. Study zone

5 A Case Study

To prove the robustness of the "OGI-GeoRen" tool, a case study was conducted in the Bouzaghlal district, referring to the Moroccan context, which is located in the north of M'diq city and belongs to the Z2 climatic zone. The district is composed of 1219 buildings, which are generally characterized by the non-structured typology "Moroccan modern house" (Figure 4).

The building stock of the case study is characterized by single-family, non-thermally insulated, and multi-story houses. The zone is composed of 1219 buildings, 82 of which are on one single floor (6.73 %), 311 on two floors (25,1%), 446 on three floors (36,59 %), and 380 on four floors (31,17 %). The average ground surface of buildings is 103 m² and the average residential area of the conditioned floor is 210 m² (without including the commercial RDC).

6 Results and Discussions

Following the definition of all necessary parameters, the "OGI-GeoRen" tool employs thermal equations from the NM ISO 13790 [15] standard to begin calculating the energy needs of heating and cooling building-by-building in a simultaneous manner for the entire study zone for each month of the year. The "OGI-GeoRen" tool takes 11 minutes to run on a computer with 8 Go of RAM and a 2,50 GHz I7 microprocessor to generate the energy needed for 1219 buildings. This conserves time and effort compared to geometric modeling cases and individual simulations of buildings, which could take a lot of time and important sources.

Figure 5 (a) presents the obtained results concerning the spatial distribution of annual energy needs in the heating and cooling of every building in the district in the case of the reference scenario S0 without any measure of the energy efficiency of buildings. This scenario will be useful for the first validation of the "OGI-GeoRen" tool to evaluate the differences over the obtained results by the BINAYATE software program.

The statistical analysis of this scenario shows that the needs for heating vary in a range of a minimum value of 35,82 KWh/m2/y to a maximum value of 113,99 KWh/m2/y with an annual average of 61,35 KWh/m2/y depending on the different spatial dispositions and every building's characteristic, whereas the cooling needs are between a minimum value of 23,50 KWh/m2/y and a maximum value of 78,26 KWh/m2/y with an annual average of 44,74 KWh/m2/y.

Figure 5 (b) shows the obtained results of the suggested energy renovation (S_RTCM) where the whole buildings of the study zone conform to the Moroccan thermal regulation (RTCM) of zone Z2. This new scenario will be useful for a double validation of the "OGI-GeoRen" tool for the evaluation of differences concerning the results obtained by the BINAYATE software program after the application of the energy renovation of the study zone.

The S_RTCM scenario allowed an important reduction of the annual average of energy needs compared to the initial scenario (S0); it moved from 106,09 KWh/m2/y to an average of 43,90 KWh/m2/y, which is equivalent to a reduction of 44,74 KWh/m2/y to 28,02 KWh/m2/y in cooling and of 61,35 KWh/m2/y to 15,88 KWh/m2/y in heating.

The difference between the energy needs of the scenario from reference S0 and the optimal scenario S_RTCM presents the annual energy savings that can be obtained if the total of the buildings in the study zone conforms to the Moroccan thermal regulation. The calculated results show that the energy savings can reach up to 13,566.602 MWh/y which is equal to an energy gain of 54.73% with total conformity (100%) of buildings to the regulation (RTCM).

To compare the results of this study and the previous work, the bibliographical search carried out in scientific databases, Google Scholar, and Scopus using different keywords related to urban energy renovation at a large scale returned no similar study conducted in the Moroccan context except for the study [31] conducted by the same authors of this article. However, the total of the studies found was applied at the scale of individual buildings with different software, inputs, conditions, and parameters, which makes the comparison of results difficult and somewhat misleading.

The previous study [31] was conducted in the same zone of study which is the center of this present work; its methodological framework was based on a different approach than the one used for this study. The authors used the archetype approach to build reference buildings for the entire building stock of the neighborhood. Therefore, the results of the thermal simulations of the archetypes through the BINAYATE software program were generated for the entire buildings of the neighborhood with the help of the GIS tool. The results of the study show that the implementation of energy renovation at a large scale conforms to the Moroccan Thermal Regulation (RTCM), which provides an average energy gain of 52.72% at the scale of the neighborhood.

The comparison of energy gains between the two studies shows very approximate values (52.72% vs. 54.73%). This can be justified by the use of the same energy model NM ISO 13790 [15] on which the BINAYATE software program is based and the "OGI-GeoRen" tool for the calculation of energy needs. Similarly, the small difference between the two gains can be explained by the different approaches followed, notably the process of segmentation and the generalization of results according to the archetype approach against the detailed simulation of the study zone according to the building-by-building approach.

Figure 6 represents a sample of 20 buildings chosen randomly from the study zone with diverse characteristics and spatial dispositions. Every building was modeled and simulated individually by the BINAYATE software program [11] according to S0 and S_RTCM scenarios. Next, the total obtained energy needs for heating and cooling of every building were compared and evaluated against the results obtained by "OGI-GeoRen" tool for the referential scenario (S0) and the (S_RTCM) scenario after the energy renovation via the following formula:

$$\partial E_{H,nd\,(B_i)}\,(\%) = \frac{E_{H,nd\,(BINAYATE)} - E_{H,nd\,(OGI-GeoRen)}}{E_{H,nd\,(BINAYATE)}} \times 100 \quad (5)$$

- $\partial E_{H,nd\,(B_i)}$: Deviation of the heating energy needs
- $E_{H,nd\,(BINAYATE)}$: Heating energy needs simulated by BINAYATE
- $E_{H,nd\,(OGI-GeoRen)}$: Heating energy needs simulated by the "OGI-GeoRen" tool

$$\partial E_{C,nd\,(B_i)}\,(\%) = \frac{E_{C,nd\,(BINAYATE)} - E_{C,nd\,(OGI-GeoRen)}}{E_{C,nd\,(BINAYATE)}} \times 100 \quad (6)$$

- $\partial E_{C,nd\,(B_i)}$: Deviation of the cooling energy needs
- $E_{C,nd\,(BINAYATE)}$: Cooling energy needs simulated by BINAYATE

- $E_{C,nd\ (OGI-GeoRen)}$: Cooling energy needs simulated by the "OGI-GeoRen" tool

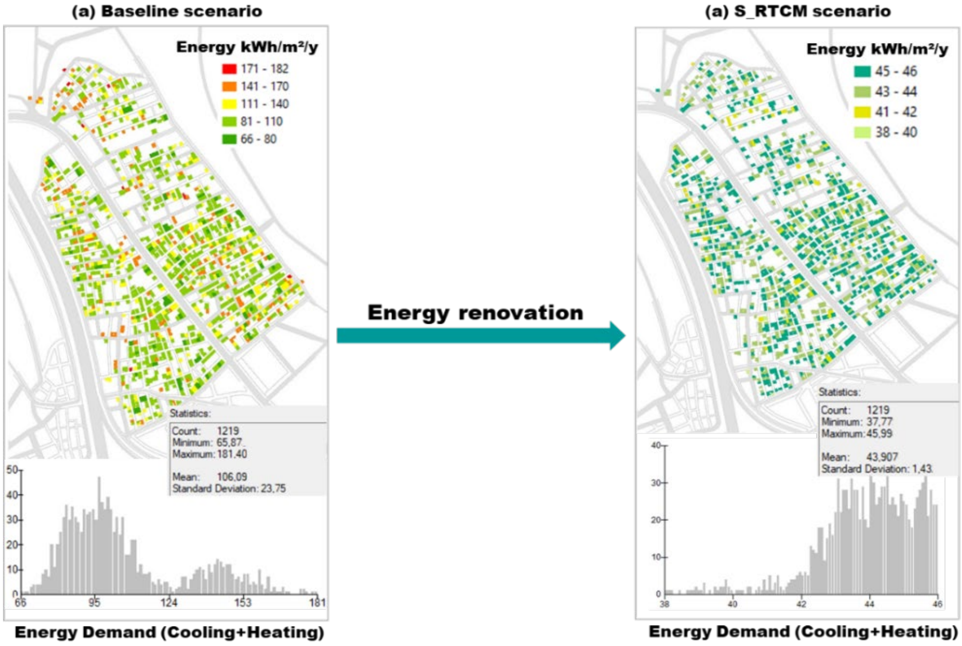


Fig 5. Spatial distribution of annual energy needs of heating and cooling for each building of the district in the case of the baseline scenario (a) and the case of an optimal energy renovation conformal to RTCM (b).

Building	Ground floor level	Number of floors	Area (m²)	Conditioned Area (m²)	Number of facades	Orientation of main facade	Glazing area (m²)	WWR (%)
B1	commercial	3	194,63	356,69	2	NO	32,43	9,68
B2	commercial	3	184,14	335,81	3	SO	45,90	13,75
B3	habitable	1	74,54	64,33	1	N	4,31	4,10
B4	commercial	4	107,99	287,46	1	NE	17,05	4,54
B5	habitable	2	102,36	181,10	2	N	23,17	9,54
B6	commercial	4	121,78	326,63	1	NO	19,52	4,90
B7	habitable	1	66,94	57,07	1	NO	3,67	3,62
B8	habitable	4	168,02	610,07	3	NE	84,92	13,32
B9	habitable	1	94,39	83,01	2	NE	11,06	9,45
B10	commercial	2	172,96	157,32	2	NE	17,22	10,71
B11	habitable	3	82,08	214,32	2	E	31,78	9,68
B12	habitable	3	82,87	216,53	2	E	14,38	4,36
B13	commercial	2	119,97	106,91	1	N	6,18	4,61
B14	habitable	4	94,50	331,76	1	NO	21,64	4,55
B15	commercial	2	112,05	99,70	2	NO	12,56	9,89
B16	commercial	4	98,27	260,33	1	NO	17,41	4,91
B17	habitable	1	126,76	113,54	1	SO	5,95	4,37
B18	commercial	2	113,90	101,45	1	NO	6,21	4,85
B19	commercial	4	103,40	271,03	1	E	17,14	4,26
B20	commercial	2	69,71	59,80	2	N	9,67	9,49

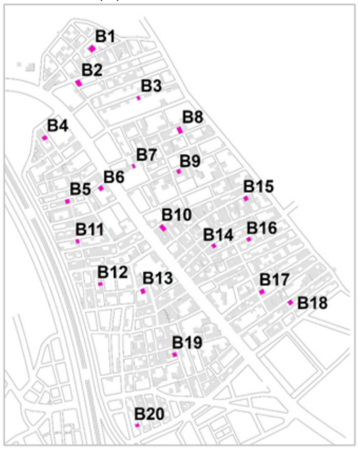


Fig 6. Buildings of validation.

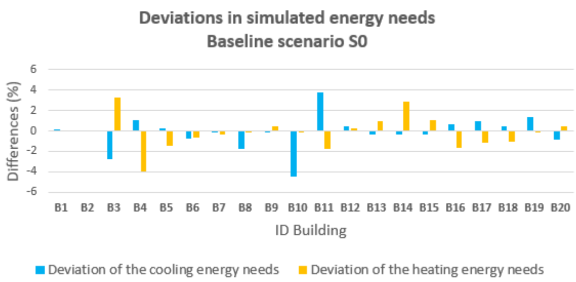
Subsequently, the uncertainty indexes were calculated for evaluating the global deviation of the "OGI-GeoRen" tool compared to the BINAYATE software. The NMBE allows for the analysis of the average magnitude of errors of simulation. However, the CV(RMSE) gives more value to the most important errors. Tables 2, 3, and figure 7 below summarize the whole results and comparisons. The analysis of the results presented in figure 7 and table 2 for the S0 scenario without any measure of energy efficiency shows that the distribution of deviations between the BINAYATE software program and the suggested "OGI-GeoRen" tool for cooling varies in a weak interval with half of the negative values and half of the positive values (min deviation = -4,43% and max deviation = 3,81%); this means that the "OGI-GeoRen" tool slightly underestimates the needs in cooling in comparison to the BINAYATE program according to the case of the building. Similarly, for the distribution of differences for heating, they vary in a minimum interval -3,97% and a maximum difference of 3,26% with half of the negative values and half of the positive values, which means that the "OGI-GeoRen" tool slightly underestimates the needs for heating in comparison to BINAYATE software program depending on the characteristics of the building.

The comparison between the obtained values of uncertainty indexes CV (RMSE) and NMBE (for cooling; -0,27% and 1.71, respectively, and for heating; 0,05% and 1,61%, respectively) with the required thresholds by the ASHRAE 14 directive [20] ((CV (RMSE) ≤ 15% and MBE ≤ ± 5% in the case of monthly simulations) shows that the "OGI-GeoRen" tool complies with the directive's requirements and can be considered as a thermal simulation tool with very good predictive capacity of the energy needs in heating and cooling at the urban scale in comparison with the BINAYATE software program.

For the S-RTCM scenario, the analysis of the results of figure 7 and table 3 shows that the distribution of deviations between the BINAYATE software program and the suggested "OGI-GeoRen" tool for cooling varies in a weak interval with almost half of the negative values and the other half of positive values (min deviation= -4,94% et max deviation = 4,13%), which means that according to the case of the building, the "OGI-GeoRen" tool overestimates or slightly underestimates the needs in cooling compared to the BINAYATE software program. whereas for the distribution of heating deviations, they vary with a minimum deviation of -1,82% to a maximum deviation of 7,76%, with the majority of values positive this time, indicating that the "OGI-GeoRen" tool slightly overestimates the heating needs after thermal isolation compared to the BINAYATE software program.

Similarly, for the S-RTCM scenario, the comparison between the obtained values of uncertainty indexes NMBE and CV (RMSE) for cooling -0,34% and 2%, as well as for heating 2,65% and 4% respectively, compared to the thresholds required by the ASHRAE 14 directive [20], shows that "OGI-GeoRen" tool is capable of predicting the energy needs at the urban scale in comparison to the BINAYATE software program. in the case of an energy renovation scenario.

Finally, the uncertainty analysis shows that the "OGI-GeoRen" tool has some acceptable robustness and reliability in comparison to the BINAYATE software program for the prediction of energy needs in the heating and cooling of buildings at the urban scale in the Moroccan context, which could be very useful for urban projects of energy efficiency on a large scale, like the analysis of energy renovation strategies or urban energy planning for eco-districts and eco-cities.



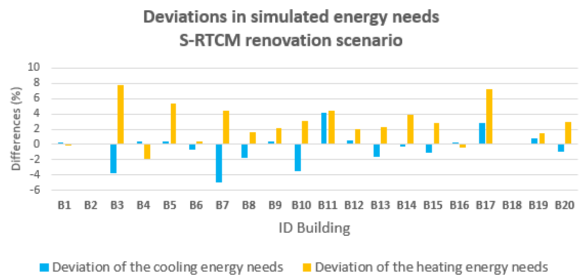


Fig 7. Deviations in simulated energy needs between the BINAYATE software program and the suggested "OGI-GeoRen" tool before and after the thermal isolation of the study zone.

Table 2. Deviations in simulated energy needs for the S0 scenario between the results of the BINAYATE software program and the "OGI-GeoRen" tool.

Building (Bi)	**Deviations in the heating and cooling energy needs**					
	COOLING			**HEATING**		
	Simulation BINAYATE (KWh/m2/y)	Simulation "OGI-GeoRen" tool (KWh/m2/y)	Cooling Deviation (%)	Simulation BINAYATE (KWh/m2/y)	Simulation "OGI-GeoRen" tool (KWh/m2/y)	Heating Deviation (%)
B1	45,90	45,81	0,20	49,48	49,47	0,02
B2	50,86	50,83	0,07	49,66	49,61	0,10
B3	58,06	59,65	-2,73	110,73	107,12	3,26
B4	29,50	29,20	1,01	43,26	44,98	-3,97
B5	38,08	37,98	0,27	59,56	60,44	-1,48
B6	36,33	36,59	-0,70	45,72	46,01	-0,64
B7	58,19	58,23	-0,07	111,14	111,53	-0,35
B8	38,13	38,81	-1,77	44,08	44,09	-0,03
B9	53,31	53,37	-0,12	101,32	100,85	0,46
B10	57,47	60,02	-4,43	75,63	75,77	-0,18
B11	39,78	38,27	3,81	55,38	56,38	-1,80
B12	37,97	37,81	0,42	58,53	58,39	0,24
B13	54,69	54,88	-0,34	79,71	78,96	0,94
B14	32,16	32,26	-0,31	53,05	51,53	2,87

B15	64,54	64,75	-0,32	81,30	80,44	1,05
B16	33,76	33,53	0,68	46,87	47,64	-1,63
B17	54,74	54,22	0,95	88,70	89,73	-1,16
B18	55,75	55,50	0,44	77,57	78,38	-1,05
B19	38,37	37,85	1,35	47,97	48,02	-0,10
B20	63,55	64,10	-0,86	90,26	89,84	0,46
Uncertainty indexes (%)						
Indexe	**COOLING** (%)			**HEATING** (%)		
NMBE (%)	-0.27			0.05		
CV (RMSE) (%)	1.71			1.61		

Table 3. Deviations in simulated energy needs for the S-RTCM renovation scenario between the results of the BINAYATE and "OGI-GeoRen" tool

Building (Bi)	**Deviations in the heating and cooling energy needs**					
	COOLING			**HEATING**		
	Simulation BINAYATE (KWh/m2/y)	Simulation "OGI-GeoRen" tool (KWh/m2/y)	Cooling Deviation (%)	Simulation BINAYATE (KWh/m2/y)	Simulation "OGI-GeoRen" tool (KWh/m2/y)	Heating Deviation (%)
B1	30,65	30,59	0,20	13,39	13,40	-0,05
B2	33,04	32,99	0,16	10,63	10,61	0,19
B3	21,59	22,41	-3,80	23,82	21,97	7,76
B4	23,02	22,94	0,37	18,98	19,33	-1,82
B5	25,99	25,89	0,40	17,36	16,43	5,37
B6	25,86	26,03	-0,64	18,62	18,54	0,41
B7	22,41	23,52	-4,94	20,76	19,83	4,46
B8	29,49	30,00	-1,74	13,76	13,54	1,63
B9	24,77	24,68	0,34	19,57	19,15	2,14
B10	28,84	29,83	-3,45	16,23	15,74	3,01
B11	30,30	29,05	4,13	15,18	14,51	4,38
B12	28,44	28,30	0,49	17,77	17,43	1,94
B13	23,99	24,37	-1,59	18,44	18,02	2,28
B14	23,76	23,84	-0,33	20,92	20,12	3,81
B15	30,58	30,92	-1,10	12,51	12,16	2,80
B16	25,21	25,13	0,33	19,79	19,87	-0,42
B17	24,87	24,16	2,87	19,83	18,39	7,28
B18	26,62	26,58	0,15	18,42	18,39	0,14
B19	28,53	28,29	0,86	16,18	15,94	1,48
B20	29,81	30,09	-0,94	14,15	13,74	2,88
Uncertainty indexes (%)						
Indexe	**COOLING** (%)			**HEATING** (%)		
NMBE (%)	-0.34			2.65		
CV (RMSE) (%)	2			4		

7 Conclusion

To properly conduct projects of energy renovation on a large scale, we should start by calculating the energy needs at the urban scale to diagnose the existing state, compare the urban energy scenarios, and simulate the future state of the building stock after renovation work.

This article proposed a methodological framework to reduce the standard calculation of energy needs of individual buildings at the urban scale. For this purpose, a simulation tool was developed based on the coupling between the GIS and the quasi-static, monthly, simple method of the standard NM ISO 13790. The tool is based on commonly available data and a bottom-up approach building by building to evaluate the energy performance of buildings at various spatial scales with precision and a reasonable calculation time.

The present case study is an example of a future energy renovation applied at the scale of a neighborhood, taking into consideration the Moroccan regulation (RTCM) and the thermal comfort of all buildings in the study zone. The "OGI-GeoRen" tool was used to derive the geometric input data and the characteristics of buildings efficiently, as well as calculate the energy balances and evaluate the different scenarios of thermal insulation. The results show:

- For scenario S0, the average annual needs for cooling are equal to 44.74KWh/m2/y whereas the needs for heating are equal to 61.35KWH/m2/y
- For scenario (S_RTCM), an important decrease has been observed concerning the average annual energy needs in the initial scenario (S0). Cooling went from 44.74 KWh/m2/y to 28.02 KWh/m2/y, and heating went from 61.35 KWh/m2/y to 15.88 KWh/m2/y.

Publishing these results in the form of maps that can be accessed via energy renovation cadasters may incite citizens to adopt energy efficiency measures and encourage policy-makers to launch projects of energy renovation at the urban scale, which will accelerate the energy transition in Moroccan building stocks.

To analyze the validity and robustness of the "OGI-GeoRen" tool, the adopted approach attempted to compare the results obtained from the energy simulation of 20 buildings chosen randomly from the neighborhood. The two indexes of the uncertainty of the directive ASHRAE 14 (NMBE et CV RMSE) are calculated for the validation of the tool.

- For scenario S0 with no energy efficiency measure, the obtained values have indexes of uncertainty for CV (RMSE) and NMBE equal to: -0.27% and 1.71% for cooling, while for heating: 0.05% and 1.61%, respectively.
- For scenario S-RTCM, the obtained values have indexes of uncertainty NMBE and CV (RMSE) equal to: -0.34% and 2% for cooling, whereas for heating: 2.65% and 4%, respectively.

The indexes give acceptable values concerning the requirements of the directive ASHRAE 14 for the case of monthly simulations ((CV (RMSE) ≤ 15% and MBE ≤ ± 5%). This shows that the "OGI-GeoRen" tool can predict precisely the energy needs at the urban scale in comparison to the tool BINAYATE.

Future work includes launching a cadaster of energy renovation for the study zone presented in this case study. Similarly, the "OGI-GeoRen" tool will be coupled with the method of life cycle cost (LCC) to conceive a full techno-economic tool dedicated to the evaluation of potential different measures of thermal insulation and the analysis of their economic feasibility. Another future study aims at comparing the standard NM ISO 13790 and its new version, which is the standard EN IS 52010-1 for the Moroccan context, to evaluate the probable gaps and enhance the quality of current energy balance previews. It has been noted that the new standard EN ISO 52010-1 is undergoing adjustments and calibration concerning national contexts as the standard has proposed.

Additionally, the double validation of the OGI-GeoRen" tool will be conducted to test its robustness in comparison with the dynamic simulations that were realized by referential software programs like TRNSYS, and EnergyPlus. This validation will be useful later in studying the possibilities, feasibility, and necessity of evolving the "OGI-GeoRen" tool to dynamic simulation rather than the simplified method suggested by the NM ISO 13790 standard.

Acknowledgments

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