

“URBAN ISLAND” AS AN ENERGY ASSESSMENT TOOL. THE CASE OF MOUZAIA, ALGERIA

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Residential buildings in Algeria are responsible for 41% of total country's energy consumption. In this study, a holistic approach has been adopted to analyze the building stock of a middle-sized city (Mouzaia) in Algeria according to their energy consumption. The purpose of this paper is to test the pertinence of the urban island scale as an energy assessment tool. This study is based on a statistical approach of the islands' typologies to single out a model able to estimate the energy load of a simple dwelling or for an island according to a set of indicators. Thus, Urban islands were clustered according to their geometrical and physical attributes that considers a large panel of indicators such as island's area, built-up area, compactness, porosity, land use, areal density, built density, solar admittance and the passive volume. The conclusion of this analysis shows the classification profiles of the building stock of Mouzaia according to their energy consumption with an accuracy level of 86%. Also, this model developed can be implemented to a GIS tool in order to identify within a large scale the different scenarios which could be adopted to reduce the energy load of dwellings.

Key words: Algeria, Sensitivity analysis, Existing buildings, Urban islands, Typology, Energy use

INTRODUCTION

The recent data from APRUE [01] confirms that the residential sector is responsible of about 41% of the energy end use in Algeria. Concretely, this consumption is higher for the electricity (121mtoe) than for the gas 12 mtoe..

Algeria like other countries in the world, has adopted a policy to reduce and control its energy consumption and to mitigate the GHG emissions. This policy can be presented mainly within four adopted strategies: (i) A motivating strategy which encourages the use of more renewable energy by inhabitant to attain the objective of 40% and a decreasing of 27% the carbon emissions by 2030 [01, 04]. To reach this goal, the Algerian government funds 50 % of the total cost of installation of solar water heaters and 45% of the cost to convert cars to natural gas [01, 04]. However, the experience is not well supported by the medias; (ii) pilot project strategy: where a set of prototype buildings have been already tested. However, even if the built pilot projects have got an important insulation rate, the experience showed that there is a gap between research studies and the construction results.

This conclusion highlights the importance of the monitoring in this kind of projects; (iii) Training strategy: Many architects and engineer currently trained in the area of building energy efficiency. Unfortunately, this strategy remains without real impact because of the lack of constraining legislative frame that imposes a particular constructive mode. The existing regulation (DTR) [20], which is considered as a statistic calculator, does not take into account the design parameters, it calculates only the energy budget based on the U-values of the different materials used in the studied building;. (iv) Marketing and management strategy, for which Algeria has performed a labeling system for household appliances [19]. This strategy will also be extended to the building field.

The energy policy mastering in Algeria is recent and remains conducted within a top-down approach. At the local level, the energy is not a particular subject of attention, essentially due to the cheaper cost of energy, 5 DZD/Kwh (0.05 €). Also, to satisfy the Algerians' energy demand, the Algerian government subsidies in energy are about 1.5

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to 2 billion dollars yearly [18]. Besides, considering the rapid increasing rate of urbanization in the recent years, a more constraining legislative frame could increase the cost and the duration of the operational studies, and causes eventually a delay of the presidential program which aims to build 3 million of dwellings in 15 years [04]. The prospective study of the fossil energy reserves shows a probable limitation in the oil production for the 2030's horizon of about 700 000 barrel a day, which could quietly cover the national needs [07]. However, the understanding reasons of the important energy consumption in building stock in the Algerian context have not yet been sufficiently highlighted by research in urban studies. Therefore, in this paper, we will focus our attention on the energy consumption of buildings to single out the most relevant parameters affecting the energy consumption and the impact carbon footprint in the context of Algeria. The conclusions of this work will help architects, engineers and decision makers to determine the priorities for energy conservation measures (ECMs) [08] in residential buildings, in order to reduce the environmental impact of CO₂ emissions, through the implementation of a realistic and effective action plan.

List Of Abbreviations

Kwh/m ² /y	Kilowatt hour/m ² /year
U	heat transfer coefficient
EPI	Energy performance index
Mtoe	Million Tonnes of Oil Equivalent
GHG	Greenhouse gas emission
G IS	Geographical Information System
DZD	Algerian Dinar
ECMs	Energy conservation measures
DEM	Digital Elevation Models
PCA	Principal Component Analysis

STATE OF THE ART

Energy assessment methods

The research of most relevant parameters influencing the energy demand in residential building has been widely treated in the scientific literature [09]: (i) the occupant behavior: which constitutes the most important uncertainty factor when predicting the energy demand using a simulation model. The occupant behavior varies widely and can increase the energy consumption up to 100% [16]. Several researches [03], [29], [16], [32], [25] and [22] showed that occupant behavior and profile can modify the energy demand

from simple to double of the predicted values [10], which is than very difficult to estimate. Generally, according to these studies, we can classify the behavior of occupants in three lifestyles: thrifty one, standard or normal and wasteful lifestyle which consumes energy willingly [12]. Also, it is pointed that predicting an occupant behavior is so complex that some researchers prefer studying spaces with only one person occupancy [idem]. (ii) The design factor: considered as the most studied field. There is mainly two approaches to identify the design impact on the energy demand: (a) Engineering approach [23], [05], [28] and [17], based on determinist algorithm used as a simulation model. This approach is considered by the scientific community as the most accurate one. It allows the isolation of the occupant's impact and highlights subsequently the importance of other parameters of the building design. But the simulation models' cost and their technical complexity make them difficult to generalize. Besides, this approach enables us to study the importance of new non-existing parameters especially the technological ones. (b) Statistical approach, called also historicist approach [10]. It tends to develop models of prediction based on the correlation of the energy end-use with a set of indicators obtained from the existing building stock. It is used at the macro (top-down) scale as well as at the micro scale (bottom-up) [14]. In other hand, the statistical approach is particularly used at the macro scale to appreciate the energy load of a city or country for a long-term period and it is frequently presented within a GIS-based analysis [02]. The main-used descriptors are the socio-economic data, the energy cost and the climatic conditions [16]. On the other hand, at the micro scale, the design parameters commonly used of the existing building stock used are the glazing rate, materials, age of building and household size. The statistical approach is widely used by the European community and it constitutes a legislative framing tool in various countries, such as Italy [06] and Greece [11]. It is nevertheless limited by the strict and limited use of extracted data from the existing building stock, which does not allow introducing new parameters, specifically the technological ones. (iii) Urban context: its importance has been demonstrated by a lot of researchers [23], [28], [24] and [27]. It's interpreted by the impact of climatic and microclimatic urban conditions which impact the energy demand by about 10% [23]

and estimating an increase up to 50% [24], if we add the transportation field. The urban context influences the solar admittance, lighting, ventilation quality and the urban transportation which is not the objective of this study, but other researchers had already validated this correlation [21]. Thus, a set of parameters, like density and urban heat island, describing the urban context according to its impact on the energy demand of buildings, climatic and microclimatic conditions, has been highlighted by the scientific community. (iv) Building energy systems: used for cooling, heating or lighting. This factor is incontestable and it is possible to predict its impact using the engineering method, but its introduction in a statistical approach requires a ponderous survey in terms of time and costs. Some researchers showed its impact on buildings' energy load as it has been done for example in the European project TABULA [15] and in Belgium [26].

Sampling methods

The state of the art examination lets us to classify the sampling methods into three registers: (i) the Archetype Approach: this approach is based on a DOE, a Design Of Experiments which is a generic building characterized by a set of the design parameters representing correctly the building stock. Parekh (reported by Lukas.G et al) [16] classifies the criteria of structuring a validate archetype in: (a) Geometrical criteria, (b) thermal and (c) operating systems. J.Bouyer [05], in his thesis, has performed a campaign of 2000 simulations by diversifying randomly a set of seven geometrical and physical indicators. (ii) Sampling approach: this method is based on a typology of building which are clustered according to a panel of indicators and every sample building

is assigned by its energy performance index (EPI) (Kwh/m²). To estimate the energy demand of a building, the author of this research checked the rate of similarity between the considered buildings and the identified sample. Once, the similarity is strong enough, the energy demand will be estimated by multiplying the area of the considered building by the performance energy index of the sample. The project Energy and Environment Prediction (EEP) proposes a typology based on an existing building stock which has been characterized by the heated area, façade area, age of the building and the glazing rate [13]. A typology of 100 building has been performed. The land use is not analyzed per se as a factor but introduced via the building function. The scale of analysis is the building one which is generalized [17] to the entire city by interpreting the similarities between the 100 buildings considered as reference and the building stock. Also, and based on the urban bloc as sampling, Maizia.M et al [17] have considered the typology performed by the IAURIF (Institut d'Aménagement et d'Urbanisme de l'Île de France). 25 urban blocks have been identified based on the geometrical criteria such as the areal density, built density, area, facades perimeter and the mean height of urban blocks. In the same track S.Salat [24] and Manoj Kumar [26] have leaned on the dwelling type as sampling approach. Then, every dwelling typology is characterized by its geometrical and physical criteria. Kumar Singh identifies 5 typologies for the case of Belgium and S.Salat for the French case identifies 6 typologies which are (see Figure.1 below): individual and identical individual dwelling, village type, the collective habitat continuous low, collective habitat continuous high and the collective habitat discontinuous.

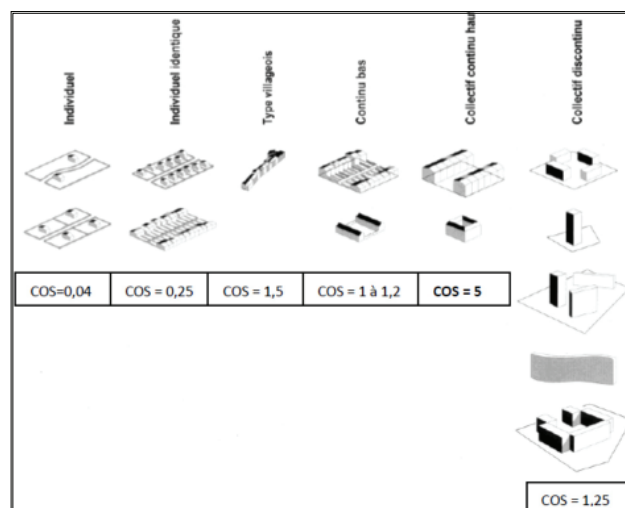


Figure 1: Built density (COS) and Housing typology [24]

This typology represents correctly all the French cities and also the countries of the Maghreb as Algeria which is our case of study. These similarities are explained by the fact that the major part of the Algerian middle-sized cities has been established at the period of the French colonization. Thus, the transposability of the sampling method is possible and it allows besides comparing the two sides of the Mediterranean. (iii) Finally, the third method tends to identify the typologies based on equal urban fragment as it has been done by S.Salat [24] who selected different fragments of 200*200m, 400*400m, 800*800m, or Steemers [28] and Ratti.C et al [23] who used Digital Elevation Models (DEM) for a fragment of 400*400m. We must note here that, by selecting this method, S.Salat [24] showed that the urban fragments characterization change with the dimension of the fragment selected which means that we cannot generalize the findings. However, this approach is a very useful to assess and compare side to side different urban fragments as density, compactness and mobility parameters correlated to the energy consumption for each urban fragment.

Methodological choice and justification

Our methodological choice is organized according to: (i) First, the most advantageous method

to evaluate the energy demand in our case is the statistical approach because it represents the real energy consumed and it takes into consideration all the factors impacting the energy demand cited above. (ii) Secondly, the choice regarding the scale for our study is argued by the fact that the scale of a building considered individually risks to eliminate the impact of the urban context, on the other hand, the neighborhood scale doesn't allow to consider the design parameters of buildings, a neighborhood could shelter in the same time collective habitat, individual dwellings or even mixed one. So, we have selected the "urban island" scale as an intermediate one between the building scale and the neighborhood one. The island scale considered as the principal unit of the urban composition allows considering both, the spatial and functional specificities of buildings. The objective of this research takes into account the pertinence of the scale of the urban island. And (iii) For our paper's purpose, we have selected the sampling approach. The scale of the sample is here considered at the island scale, and based on its land use and housing typology. The hierarchical identification and characterization of urban islands is conducted within the logic presented in the Table 1 below:

Table 1: Structure of the sampling method

Dwelling type	Chosen criteria	
Individual discontinuous	Density built	Areal density
Individual identical	compactness	Solar admittance
Collective continuous	Passive volume	Urban heating island
Collective discontinuous	Housing mean area	Housing per island
Village type	porosity	End use energy
	Island area	End use Energy/housing

Based on this table of characterization, we have, firstly, identified every single island according to its housing type by a Google Map scan within the scale of 400*400m, followed by an in situ validation to confirm the urban islands identified. Secondly, every type has been characterized by a

set of indicators as presented on Table 1. Thirdly, a sensitivity analysis is performed between the identified indicators and the energy end-use per housing. Then, based on the most important factors, an estimative model is carried out based on a multiple linear regression. Finally, and based

on the Principal Component Analysis (PCA), we have clustered our urban islands into three clusters according to their energy consumption and the most important factors. The section below presents the findings of our approach.

RESULTS AND DISCUSSION

We have selected the middle-sized city of Mouzaia as case study. Mouzaia was established during the French colonization period, located at 13km from the Mediterranean Sea (36° 28' 00" Nord

2° 41' 00" East) and it has an altitude of 113m. Its urban density is estimated to 623 inhab/km² [31]. The Climate of Mouzaia city is considered as a temperate one, hot and humid in summer, cold and rainy in winter. The average yearly temperature is 18.1°C. The mean precipitation is about 684 mm. August is the hottest month of the year with an average temperature of 26.4°C and January is the coldest month with 11.1°C as average temperature [30].

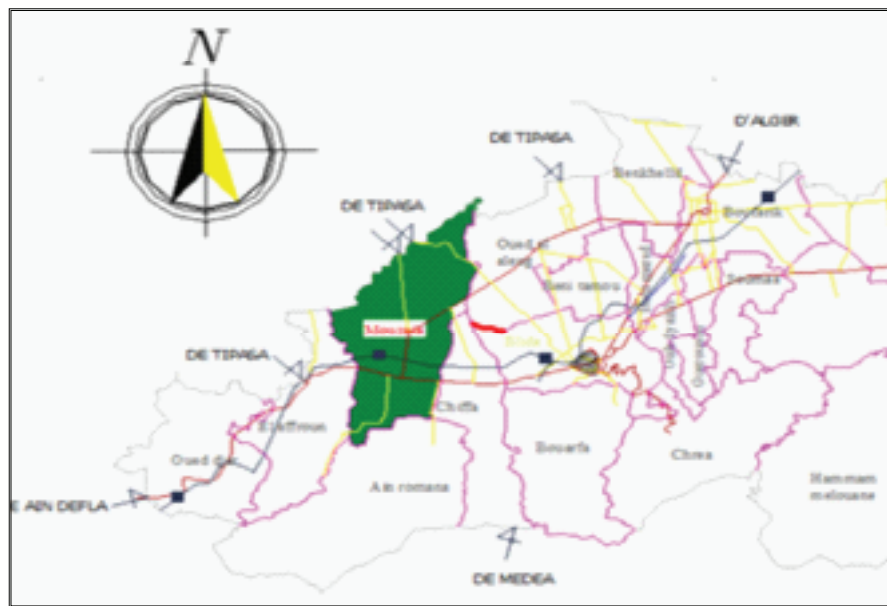


Figure 2: location of Mouzaia city [31]

Identification of Island typologies

The sampling has been done at the island scale within Google Map. 121 islands have been identified and characterized within the criteria presented in the Table 1 and the identified typology in Table 2. And, a site visit was necessary to confirm the identification of urban islands.

Table 2 below shows that the individual housing constitutes the dominant typology which is a common tendency of all the middle-sized cities in Algeria. It can also be noted that the actual tendency of urbanization is dominated by the spreading of the collective habitat which is mainly located on the city outskirts.

Table 2: Island's typology and frequency

Island typology	Island N	frequency %
Mixed	19	15.71
Individual discontinue housing	49	40.50
Individual continue housing	14	11.57
Collective discontinue dwelling	25	20.66
Collective continue dwelling	3	2.47
Equipment	9	7.43
Village type	2	1.66
Total	121	100

Sampling:

By applying the quota sampling method we have reduced the number of island to be studied from 121 to 31 respecting a good representation of the entire islands according to their frequency in the city.

Data collection and Islands Characterization

After the examination of the current state of the art, we have selected a set of indicators to characterize the urban islands selected for the study: (i) Areal density (Ad) represents the ratio of built area to the island area. (ii) Built Density (Bd) is calculated by the ratio between the sum of all the floors' built area and the island area. (iii) The compactness (S/V) determines heat loss and gain of buildings. It is estimated by the ratio be-

tween the envelope areas of the building and its volume. (iv) Passive volume corresponds to the volume part of a building which is naturally heated, ventilated and lighted. Its depth is commonly estimated by twice the height of each floor [24]. (v) The solar admittance (As) allows estimating the solar potential of an urban island or an individual building. It's estimated by the ratio between the sum of all the facades areas according to their orientation coefficients and the sum of all the areas façade. (vi) Porosity (Po) considers the urban ventilation potential. It's estimated by the difference between the volume built and the volume of the void between buildings. (vii) The Energy end use of the selected islands has been acquired from "Sonelgaz", the firm in charge to invoice the energy consumption in Algeria.

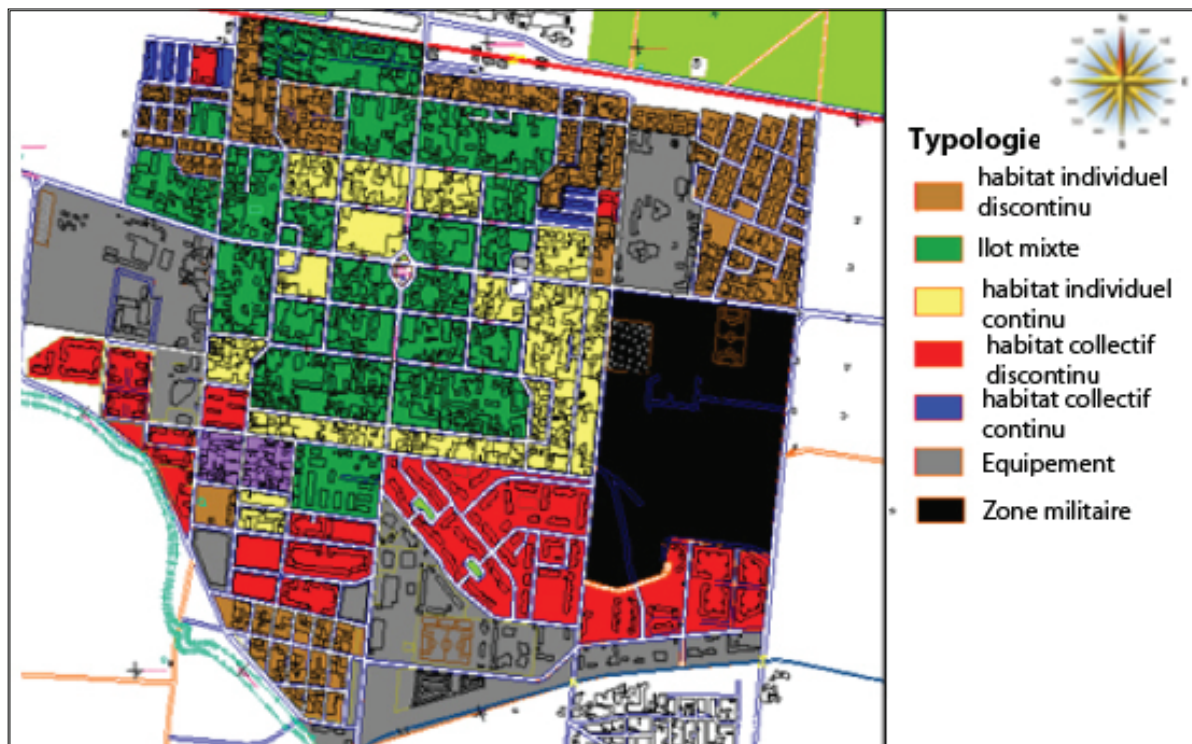


Figure. 3: Island typology map

We note that the energy consumption obtained represents the gas and the electricity. But, we choose to aggregate the data on the table 3 below for synthesis reasons. Also, we couldn't acquire all the islands' energy consumption. The islands' missing data are 17, 18, 22, 23, 24, 25 and 65 and are presented on the table by NI (Not identified). This missing data can reduce the ac-

curacy of the estimative model and reduce by the way the number of the islands studied to 21. In addition, for every single island we have identified its area, number of housing per island and its built area. The calculated and collected data is presented on the Table below.

Table 3: Island characterization

Isl	Type	Ad	Bd	Vp	C	As	E (kwh)
1	Ind-C	0.46	1.38	89	0.40	0.80	108166
2	Ind-C	0.46	0.92	81	0.39	0.80	86051
3	Ind-C	0.53	1.06	84	0.38	0.60	135441
4	Mixed	0.62	1.24	82	0.48	0.59	130316
5	Mixed	0.43	1.29	91	0.33	0.81	80709
6	Ind-C	0.42	1.26	34	0.48	0.82	98211
7	Mixed	0.62	1.24	77	0.33	0.79	86127
8	Mixed	0.62	1.24	76	0.34	0.79	132767
9	Ind-C	0.54	1.08	40	0.26	0.80	81062
10	Mixed	0.52	1.04	83	0.37	0.78	76559
11	Mixed	0.63	1.89	93	0.35	0.80	107166
12	Ind-C	0.68	2.04	80	0.30	0.79	125808
13	Mixed	0.40	0.80	79	0.34	0.80	92322
14	Mixed	0.51	1.02	74	0.51	0.81	66981
15	Mixed	0.45	0.45	85	0.57	0.80	123127
16	Mixed	0.56	0.56	80	0.52	0.80	61470
17	Mixed	0.36	0.72	89.51	0,42	0.79	N-I
18	Mixed	0.37	0.74	92.92	0,41	0.81	N-I
22	Mixed	0.35	0.70	91.79	0,41	0.80	N-I
23	Ind-D	0.32	0.64	98.98	0,43	0.81	N-I
24	Ind-D	0.41	0.82	88.3	0,42	0.79	N-I
25	Mixed	0.33	0.66	98.56	0,43	0.80	N-I
65	Col-D	0.2	1.00	100	0,40	0.81	N-I
73	C-Ind	0.92	1.84	71,77	0,29	0.80	N-I
74	C-Ind	0.55	2.2	91,44	0,29	0.81	N-I
75	Col-D	0.55	2.75	100	0.19	0.80	155382
111	Col-D	0.28	1.4	100	0.29	0.79	162147
112	Col-D	0.23	1.15	100	0.31	0.80	82330
113	Col-D	0.26	1.3	100	0.30	0.80	153020
114	Col-D	0.25	1.25	100	0.28	0.78	46489

Where: Ind-C: Individual continuous housing / Mixed: Individual+facilities / Ind-D : Individual discontinuous housing / Col-D : collective discontinuous dwelling / Col-C : collective continuous dwelling.

Predicting model

By performing a bivariate correlation (2-tailed) between the energy end-use per housing and a set of indicators we have estimated the im-

portance of each selected indicator. All the indicators show a significance rate (P value) below 0.05 except the solar admittance which affect the energy end-use by -24.9% and the built density with a negative correlation of -37.2%, as shown on the Table below.

Table 4: Bivariate correlation

Parameters	EEU/housing (R)	sig
built area	78.2	.000**
housing per island	-78.4	.000**
solar admittance	-24.9	.276*
compactness	-50.2	.02**
passive volume	-58.9	.005**
Built density	-37.2	.097*
Areal density	-68.6	.001**
porosity	-68.6	.001**

**Correlation is significant at the 0.05 level (2-tailed).

*Correlation is not significant at the 0.05 level (2-tailed)

But, once we perform a multiple linear regression, the most relevant model considers only three main indicators which are the housing mean area, areal and the built density (see table. 6). The model

has a coefficient of correlation (R) of 0.927 and R² 0.86 which means that the model has a good potential of estimation. We have selected the third model according to its higher value of the R².

Table 5: Accuracy of the estimative models

model	R	R ²	R ² adjusted	Standard error
1	,816	,665	,647	114,55581
2	,887	,787	,763	93,91634
3	,927	,860	,835	78,30257

Table 6: The selected (3) estimative model

Model	Coefficient	Standard error	Sig.
(Constante)	355,024	74,829	,000
Housing mean area	,558	,170	,004
Areal density	830,684	172,090	,000
Built density	-132,655	44,480	,008

Using this model we can estimate the energy end-use per housing based on the model described on the table above. Then, all the city of Mouzaia could be represented and we can also use this model to implement a Geographical Information System (GIS) to assess and compare the different scenarios by changing the input values which are the areal density, the built density and the mean area per housing in the model equation presented below.

$$EEUh=355.024+0.558HMA+830.68Ad-132.65 Db$$

With:

EEUh - is the energy end use per housing

HMA - is the housing mean area

Ad - is the areal density of the island

Db - is the built density

Energy profiles

To carry out the islands energy profile we have performed Principal Component Analysis based on the most relevant indicators obtained by the estimative model which are: the housing's mean area, areal density and the built density. We have added to the PCA, the compactness and the density of housing per island. This PCA would help architects and urban designers to improve their architectural housing design at the earlier stage. The PCA's representation quality is 82.96% which means that the typology of urban islands is correctly presented.

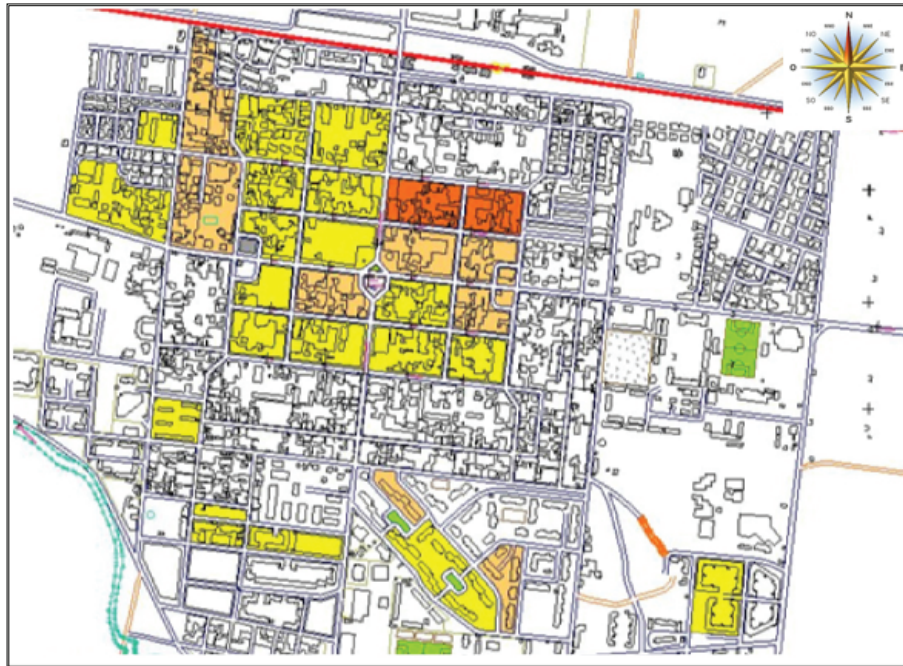


Figure 4: Islands selected by the quota method

Based on this PCA representation, we have performed a scatter diagram of the 21 island and we have marked them according to their correspondent clusters. We can distinguish three classes: (a) Cluster 1 represented by the red color and it has a frequency of 52.4% on our sample. It is characterized by the most important Energy end use per housing, areal density and mean area per housing. In the other side, this class has the weakest rate of housing per island and built density. Its compactness is average to intermediate between the two classes 2 and 3.

(b) Cluster 2 represented by the orange color and its sample frequency is 19%. It is mainly composed by individual continuous housing and mixed islands. The energy end use of this class is average between the classes 1 and 3. It's characterized by an average areal density, built density and mean area per housing. Its compactness is also average but we note that the most compact island is present in this class and the same island has the weakest value of built density and housing per island.

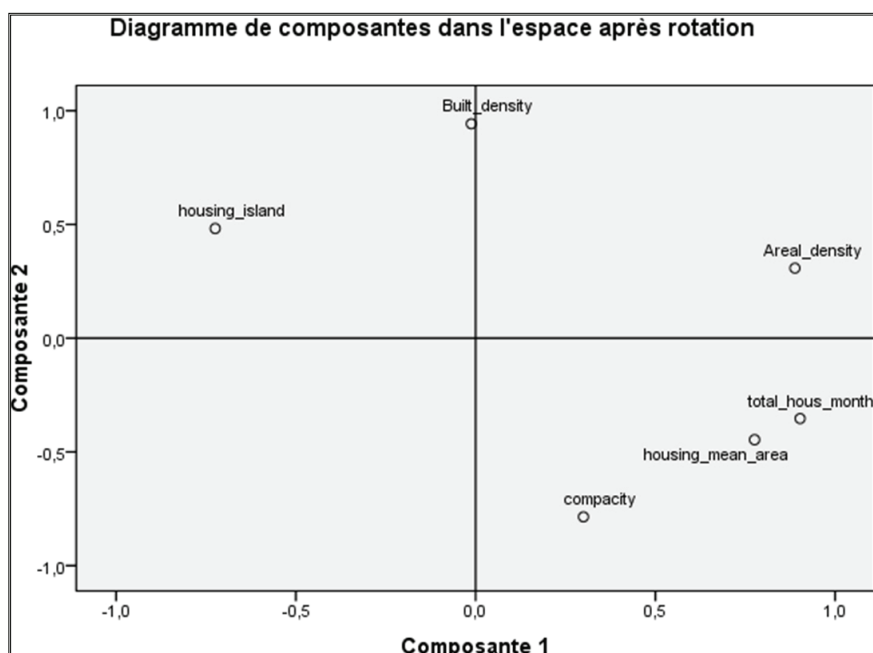


Figure 5: The PCA map

(c) Cluster 3 represented by the green color and it represents 28.6% of our sample. It represents the best cluster in term of energy consumption per housing compared to cluster 1 and 2 and it's only composed by the collective discontinuous dwellings. This cluster has the most important value of built density and housing by island. It has the weakest rate of areal density, mean area per housing, and compactness. The compactness is calculated at the island scale and if we consider the compactness per dwelling, the

value has to be lesser. This could be explained by the calculation method which considers the entire collective dwelling per island. If we take an island of collective dwelling we can get two rate of compactness, the first one at the island scale, which we have considered in the PCA performed. And the second one could be calculated at the scale of the dwelling where the compactness has to be lesser and explain more better the situation of the compactness in this cluste.

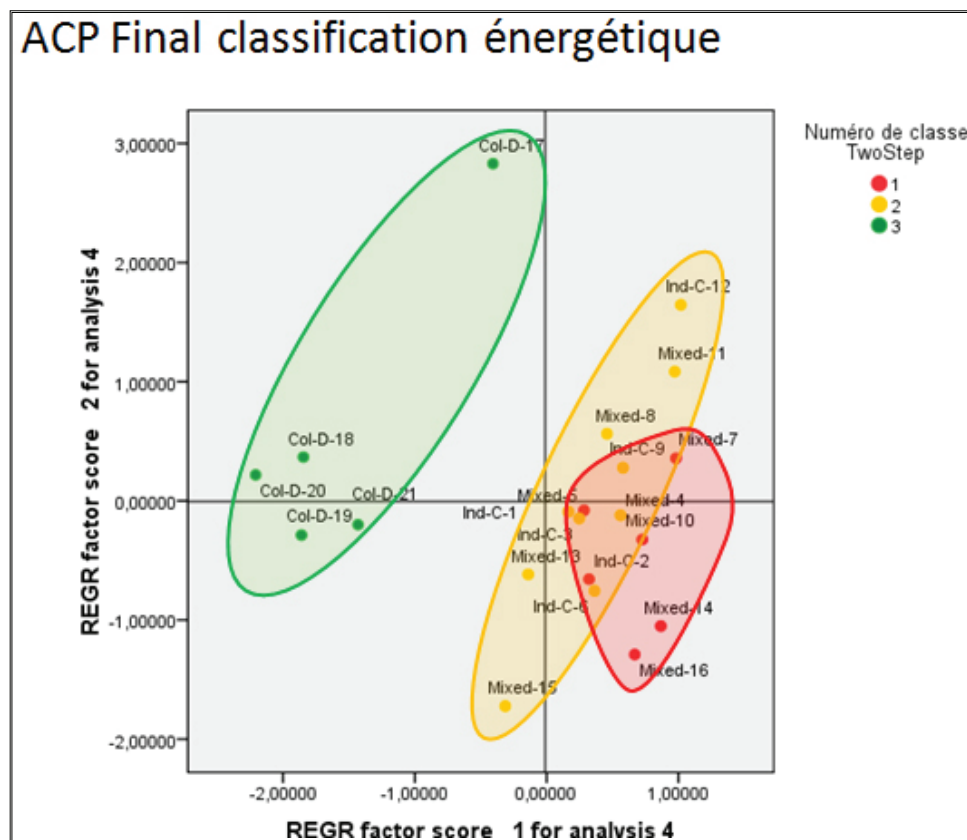


Figure 6: Islands classification

CONCLUSION

In this paper we choose the urban island as an energy assessment tool and selected Mouzaia, a middle-sized city in Algeria, to test the pertinence of the urban island scale. We selected the statistical-based approach instead of the engineering method because the purpose is to study the real impact of the urban island's parameters on the energy consumption which is very difficult to estimate using the engineering one. The sample method was based on housing typology and land use. Every urban island is characterized by a set of indicators to correlate them with the energy consumption per housing. We have carried

out an estimative model based on the built density, areal density and the housing's mean area. Also, we have performed an island energy profile basing on a PCA, and by considering in addition to the indicators cited above, the density of housing per island and the compactness. Three energy profiles were identified and the most efficient island, in our case study, is the collective discontinuous one. Our findings match the results of S.Salat [24] and Giuliano [10] who has performed for the region of Lombardy in Italy a model to predict energy end use based on the compactness factor and his model was above 70% of accuracy. In our case, the compactness has a determination coefficient of 50.2% which is

closer from the Giuliano [10] model. This difference could be explained by impact of the occupant behavior which varies from country to country and city to city. The developed model could be also implemented to a GIS tool which allows a large scale study to compare the scenarios of the potential saving energy according to the variation in terms of the built density, areal density and the housing's mean area. Also and finally, the island scale could also be considered to study in addition the housing parameters, other phenomenon such as microclimatic phenomenon in particularly the impact of urban heat island.

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