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Parametric Urban optimization by balancing energy performance and environmental quality applied to Residential Buildings in four different climates in Morocco

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Abstract. As a developing country, Morocco has maintained the same definition for social housing in the past decades. A definition where housing affordability triumphs over efficiency in both the building and exploitation phases. This paper aims to put together a rational design approach to minimize energy demands in social housing residential complexes. Thus, the project aims to improve on the quality of the subsidized social houses in the country. The analysis focuses on 4 thermal zones of the national thermal map, by working on 4 cities which are Agadir, Driouch, Marrakech and Meknes. Our main objective is to explore the trade-offs of different urban distributions on the overall energy performance in a residential complex. Henceforth, this approach puts together a parametric design methodology which allows automating the process of thermal and lighting simulation, using Grasshopper. The approach resulted in a total number of 5 994 iterations for each of the chosen regions of analysis. The project therefore explored the impact of chosen discrete values of various factors (Building Typology, Orientation, distance between buildings, Window/Wall Ratio) on the overall energy consumption and the natural light performance, by evaluating annual energy consumption, Monthly Load Matching Index, LMI, and Spatial Daylight Autonomy, SDa.

1 Introduction

Since setting up its first national plan for social and economic development between 2000-2004, the kingdom of Morocco has multiplied its efforts to reduce socioeconomic disparities. The real estate market is at the heart of this strategy since it is a market with great economic impact and several social and political leverages. Since the beginning of the millennium, the country has set a production target of 150,000 housing units per year with the aim to overcome the existing 1,855,751.00 housing deficit. Furthermore, the lack of any traditional sources of energy in the country has pushed the Kingdom of Morocco to invest in finding alternative paths into reducing its dependency on the international energy Markets, as it imports 97% of its consumed energy. The 2030 Moroccan energy plan sets a clear goal to raise energy production from sustainable sources, as well as the national efficiency in consumption of the existent energy. It is very essential to indicate that 34% of total final energy consumption is used by the building sector, of which 27% was consumed by residential buildings.

This national aspiration has resulted in the creation of the first thermal regulation for construction in Morocco, TRCM. This means that to achieve the aforementioned goals, real estate developers have to combine affordability with durability in their coming projects. Meaning that new social housing projects need to integrate core elements and strategies to increase their energy efficiency without impacting their selling prices.

2 Background

Social housing is an essential component of the kingdom's socio-economic strategy. A national priority that aims to reduce the accumulated housing deficit, while guaranteeing a better quality of life. This is even more relevant with the advent of the great trend towards urbanization, the transformation of the social fabric towards more nuclear families and the great population boom that the world and the country are experiencing. However, the building sector in general remains the largest energy consumer in the nation. Hence the need to find an optimal point between the creation of increasingly cheaper housing, by implementing the principles of energy efficiency. A local aspiration but on an international scale. Indeed, almost all countries in the world are currently facing this problem. A situation that requires not only an increase in the number of homes produced, but also an increase in the quality of the homes offered, in addition to a reduction in purchase prices.

Several collaborative and research projects have investigated the possibility of combining these two principles. Through collaboration with the government local Lafayette in Colorado, the National Laboratory for Renewable Energies, NREL, had proposed a Pilot Project for social housing integrating better energy efficiency. The project is called "Paradigm Pilot Project", through which the government was able to produce prototypes of residential complexes, intended to improve the quality of life and housing in the most impoverished regions of Colorado, United States [1]. On a similar level, O.D. Gulbin, R.Fryer and A.C.A.Ferreira carried out a study on the recommendations to be incorporated into the design of energy efficient buildings in the Philadelphia region. The study was based on the energy comparison of a reference building and the improvements needed to be adopted. This study also produced a design appropriate to the context of Philadelphia and which guarantees a better quality of life for these inhabitants. In another context, A. Hikmat and N.A. Shorouq carried out a design optimization study for sustainable social housing in arid and semi-arid environments,"Aaqaba Housing Project" and"Abu Alanda Housing Project"[2]. The two researchers found that the performance of the proposed model mainly depends on the installation region. Indeed, this model could achieve 50.4% of the reduction in annual energy consumption, in addition to 43.5% of the reduction in annual water consumption.

3 Methodology

3.1 Followed Approach

The approach focuses on automation of the calculation process. The first step is the generation of the urban forms or typologies to be analysed. Enriched with multiple data which stays constant such as schedules, construction materials, heating and cooling setpoints in addition to the inputs to be iterated which WWR and distance between buildings. The architecture is generated using grasshopper and implemented within the Rhino 3D environment. The honeybee/ladybug tools are the set of libraries used to enrich the model and run to simulation, since they're directly linked to calculation engines Energy Plus and Radiance. The input and outputs are linked to an iteration and recording grasshopper library called colibri which allows discrete modification of the inputs and recording of all elements in an excel sheet. The resulting excel sheet is then used as basis for analysis and conclusions[3].

3.2 Analysed inputs

3.2.1 Typology

Typology is a very important input in the context of our project. It is the first element defined in a construction project. It is therefore very important to identify the optimal form to be used dependent on the constraints of the climate in which the project will be implemented. The purpose of this study is to squeeze maximum benefits from passive strategies[3-4] in order to define better social housing products for demanders in Morocco. This analysis will provide guidelines to architects on orientation, WWR and distancing between buildings in order to maximise both profit and comfort for end-users. The typologies taken into consideration are set in figure 01. The set up inputs are chosen in accordance with the Moroccan context and the needs of the "Omrane Group", as exposed in Table 01.

3.2.2 Glazing Ratios

WWR is an important input while analysing energy consumption as well as daylighting. Since change in the WWR impact in a reversive way daylighting and energy consumption[3,5]. In Moroccan context orientation is a very important input, the interaction of each face of a building are different from one another. Therefore, we have set up the parametric analysis to change WWR for each of the facades separately which will allow to identify precisely which of the facades have important impact on the study.

Table 01. Simulation Parameters which are fixed (Set in accordance with the local needs)

Parameter		Value
Heating/Cooling Setpoints		20°/26°
Loads	Lighting:	10 W/m²
	Occupancy:	1,8 People/m²
	Equipment:	10 W/m²
Schedule Weekdays	Lighting:	(00:00-07:00 / 09:00-18:00 | 0%) (08:00-09:00 / 18:00-19:00 | 50%) (07:00-08:00 / 19:00-00:00 | 100%)
	Occupancy:	(09:00-18:00 | 25%) (00:00-09:00 / 19:00-00:00 | 100%)
	Equipment:	(23:00-07:00 / 09:00-11:00 | 5%) (08:00-09:00 / 14:00-18:00 / 22:00-23:00 | 8%) (19:00-22:00 | 10%) (07:00-08:00 / 11:00-12:00 / 18:00-19:00 | 25%) (13:00-14:00 | 46%) (12:00-13:00 | 60%)
Material prop.	Walls	1,26 W/m².K
	Roofs	1,50 W/m².K
	G. Floors	1,50 W/m².K
	Windows	3,00 W/m².K
Infiltration		1.19 ACH/h
Shading		None applied
Floor height		3.00 m

3.2.3 Distance between buildings:

In the context of social housing the government allows further financial benefits for developers which meet certain conditions on the number of houses constructed within a single project. This means that social housing products in Morocco are generally constructed in form of complexes and neighbourhoods. This means that it is very important to analyse the impact of distancing between building, since it provides natural ventilation and shading. Essentially, the direction of distancing is set in an independent manner which will allow to deeply verify each of the distances to be studied and taken into consideration. This input allows to also study the impact of interspacing and reduction of exposed surface depending on typology used.

3.3 Analysed outputs

3.3.1 Evaluation of the energy demand

The definition of a social housing apartment, as prescribed in the General Moroccan law, (code des impots) does not specify any integration of any cooling and heating technologies. This side is left to the appreciation of the end consumer. The energy demand is then evaluated using an ideal HVAC system, other electrical consumption is taken into consideration in the simulation but is not part of the analysed outputs. The set use schedules follow an approximate interpretation of the behaviour of a standard Moroccan family. Once all simulations are finalized, we set up an initial filtering process using the overall yearly energy consumption per m² thresholds as defined in the thermal regulation of construction in Morocco. These thresholds in our case are used to filter resulting data into a readable analysis diagram.

3.3.2 Evaluation of the energy production

Renewable energies are an important part of the active strategies used to establish a Near Zero Energy Building. In this context, only PV production is taken into consideration. It is of course possible to install PV panels on the roofs as well as on the façades. Unfortunately, BIPVS are not in the scale of the affordable for social housing project in Morocco. Therefore, only roof PVs are taken into consideration in this project. Produced energy is estimated through the solar potential these surfaces[3-5]. Due to local laws, excess in energy production cannot be injected in the General Electric Network[1]. Therefore, the definition of a NZEB based on annual energy balance is of no

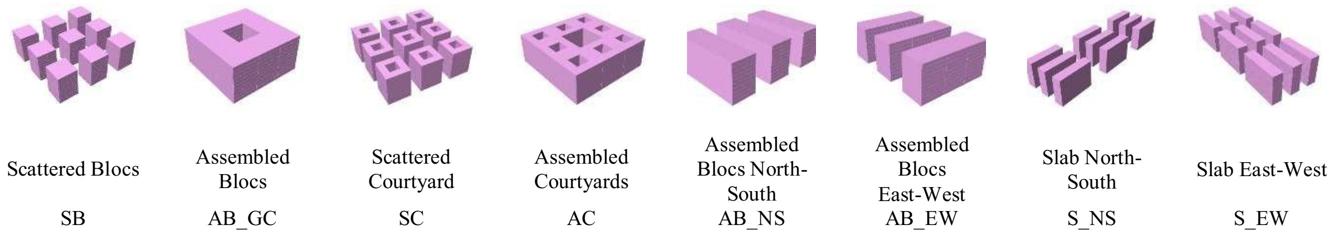

Fig. 01. Variations of typology used in the analysis

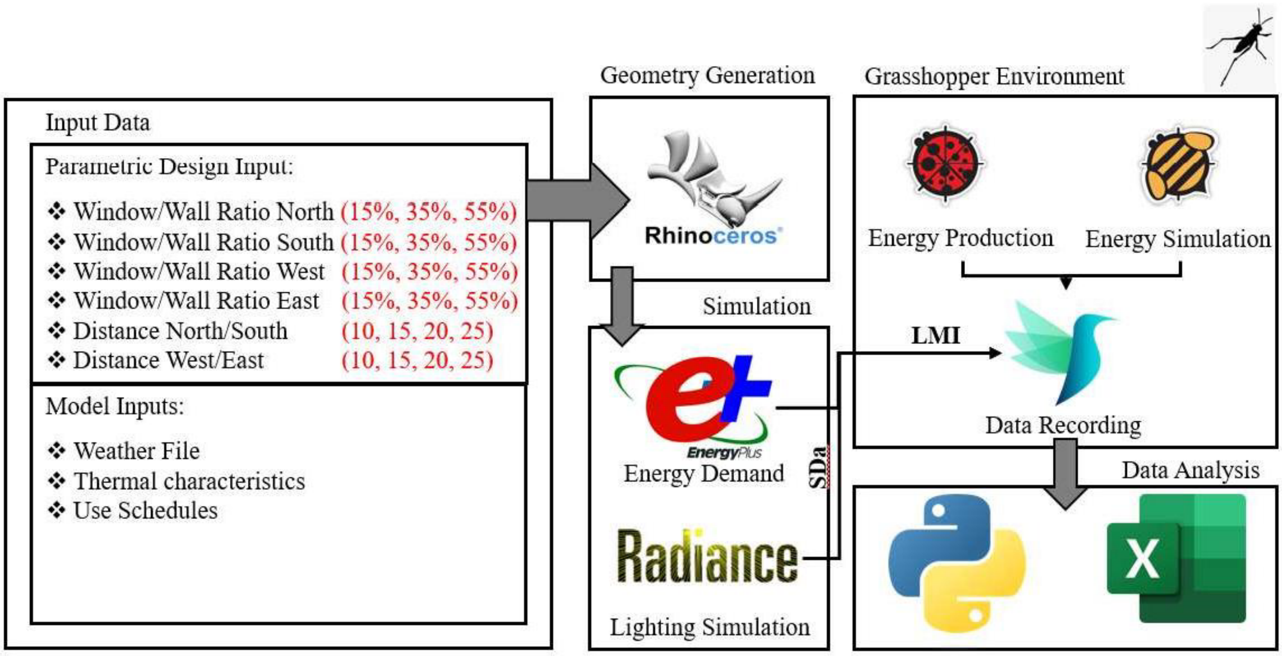

Fig. 02. Schema of the Workflow set for the proposed analysis

Table 02. General climate characteristics of the analysed regions

	Meknes	Driouch	Agadir	Marrakech
Min temperature in °C	0.70	2.90	3.00	2.00
Mean temperature in °C	17.60	18.50	19.30	20.30
Median temperature in °C	17.60	18.50	19.30	20.30
Max temperature in °C	43.30	37.50	42.60	45.80
Sum of global horizontal radiation in kWh/ (m².a)	1985.00	1948.00	2045.00	2084.00
Sum of diffuse horizontal radiation in kWh/ (m².a)	582.00	662.00	680.00	592.00
Sum of direct normal radiation in kWh/ (m².a)	2317.00	2122.00	2214.00	2454.00
Average wind speed in m/s	3.00	3.00	3.20	2.50
Average relative humidity in %	64.00	68.80	67.40	52.20

particular interest since the seasonal excess in production cannot balance the need in other seasons. Therefore, the matching between energy production and consumption will be done on a monthly basis, through the Load Matching Index.

3.3.3 Load Matching Index -LMI-

Standard definitions of Near Zero Energy Building take into account the yearly balance between energy production and energy consumption. Such definitions neglect the ability need for punctual synchronization between production and demand on shorter timeframes than a year. In this case, we opted to implement a definition which compares demand and production on a monthly basis. Thus, the use of Load Matching index (LMI). The index allows to understand the exchange in energy on a monthly basis[3]. Which we define as the following:

$$f_{load} = \frac{1}{N} \times \sum_{year} min\left[1, \frac{g_i(t)}{l_i(t)}\right] \quad (1)$$

g represents energy generation values, l is the energy load, i represents the energy carrier and t is the time interval used (hours, days or months) N corresponds to the number of data samples in our case 12.

The study is meant for a social housing development context which means that only roof PV panels are taken into consideration.

3.3.4 Spatial daylight Autonomy-sDA-

Natural lighting is an important source organic and psychological uplifting. It is very important to integrate a measure of the natural daylighting quantity received since it changes lives and raises productivity. sDA was chosen as an index since it represents the measure if a space receives proper lighting during operation hours[3-5]. Of course, in the case of social houses in Morocco operating hours would be between 8:00 and 18:00, Since the majority of families in Morocco living in these social houses have one stay at home parent. Daylight simulations are based on the radiance engine, due to the complexity of the calculation needed to be done, it is important to optimize calculation and time and needed precision of the results in order to facilitate the process of iteration needed for the project.

4 Climatic Analysis

4.1 Overview and Method

The weather analysis has been carried out for four distinct locations. Standard weather data have been exported from the software tool EPWMap ladybug website. The data have been analysed using Grasshopper as well as custom Python scripts.

Weather data have been exported from EPWMap ladybug website in EPW format. This way, the analysis could be carried out for the exact same weather data as were used for simulation. For Meknes, Agadir and Marrakesh, weather station locations were used. Weather data were calculated for a typical recent period, with radiation data based on recordings between 1991 and 2010 and temperature data based on recordings between 2000 and 2009. The analysed weather locations are summarized in Table 2.

Table 03. Location Characteristics for the analysed regions

	Meknes	Driouch	Agadir	Marrakech
Latitude	33.9 °N	35.0 °N	30.4 °N	31.6 °N
Longitude	5.5 °W	3.4 °W	9.6 °W	8.0 °W
Altitude	549 m	303 m	23 m	466 m

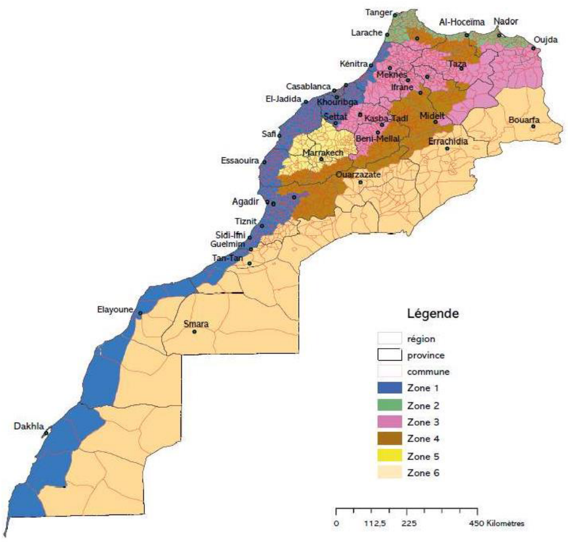

Fig. 03. Thermal Zoning Map of Morocco

Statistical indicators of meteorological variables in the different climates are summarized in Table 2. Average temperatures have only limited informative value for building design. Minimum temperatures lie between 0 °C and 3 °C for all locations. Maximum temperatures vary between 37.5 and 45.8 °C, but their significance is also limited: for instance, Driouch has the lowest maximum temperature but also a rather challenging climate for cooling, as discussed below. The annual sum of global horizontal radiation does not differ much for the different locations, whereas the breakdown between diffuse and direct radiation does to some extent. Finally, the selected locations differ in terms of wind speed and air humidity.

4.2 Comparative analysis

A rough idea of the different climates in terms of heating and cooling needs can be obtained by counting days of the following categories:
- "Cold days": days in which the average temperature lies below 15 °C, during which heating may be needed
- "Hot days": days in which the minimum temperature is above 20 °C, during which active cooling may become necessary
- "Warm days": days belonging to neither of the two previous categories, during which night-time ventilative cooling is possible and comfortable conditions may be obtained using neither active cooling nor heating.

Figure 1 shows the numbers of days in each category for the four selected locations. Agadir's oceanic climate is characterized by the highest proportion of "warm" days in which neither active cooling nor heating might be necessary. On the opposite, Driouch has the highest number of hot days of the four locations but also the second highest number of cold days.

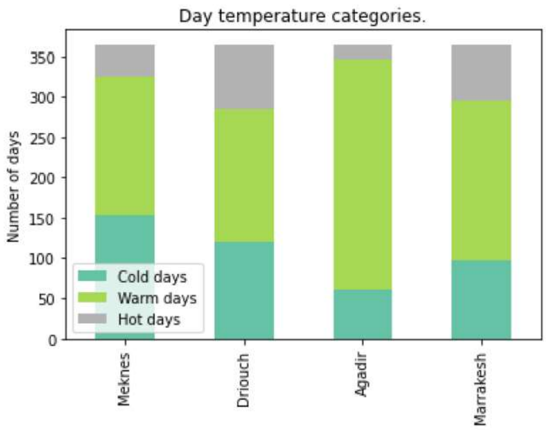

Fig. 04. Number of cold (mean temperature under 15°C), warm and hot (minim temperature above 20 °C) days in the different locations

Table 04. Number of cold (mean temperature under 15°C), warm and hot (minim temperature above 20 °C) days in the different locations

	Meknès	Driouch	Agadir	Marrakech
Cold days	152	120	61	97
Warm days	174	165	286	199
Hot days	39	80	18	69

4.3 Conclusions

4.3.1 Meknes

Meknes has a relatively long but mild heating-dominated period: 150 days with daily average temperatures between 5 and 15 °C. The summer is characterized by warm days and mostly cool nights, with only a few bursts of considerably higher temperatures, which do go beyond 40 °C.

The weather is sunny with a high share of direct solar radiation (and a relatively low amount of diffuse solar radiation).

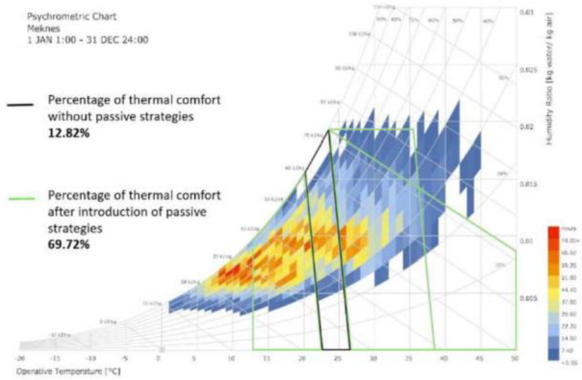

Fig. 05. Psychometric Chart of the city of Meknes

Proposed Solutions:
- Orientation of building is aligned North-South
- Direct air flows are not recommended
- Raised openings in the interior walls
- Medium openings (20 to 40%)
- Thick and massive walls and roofs with phase shift time over 8 h

4.3.2 Driouch

The climate in Driouch is subject to strong seasonal variations but rather low daily variations. Night-time temperatures above 20 °C and even 25 °C are frequent during the summer, limiting the possible impact of ventilative cooling. The amount of diffuse solar radiation is the highest in the considered locations, making the use of fixed shading more challenging. The summers are more humid than in Meknes.

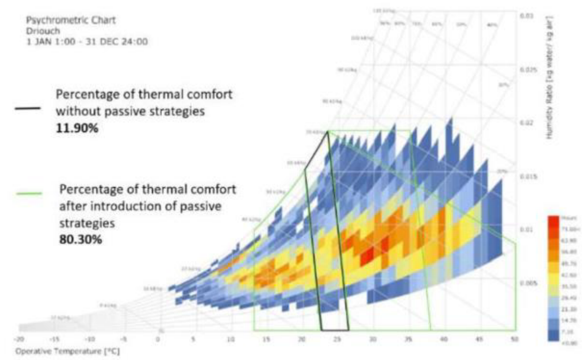

Fig. 06. Psychometric Chart of the city of Driouch

Proposed Solutions:
- High thermal inertia for the summer
- Need for passive heating during cold periods

- Dry climate reflected by low relative humidity (below
- 40% for 40% of the year), need for integrated direct cooling by evaporation especially during the summer.

4.3.3 Agadir

Agadir's climate is subject to rather low seasonal variations, excepted for a few days (and nights) of extremely high temperatures. Compared to other locations, solar radiation (especially its direct component) is reduced in the late summer. Conversely, solar radiation is consistently high during the winter, so that passive solar gains can be used. Agadir has a rather high average relative humidity in comparison to the other locations.

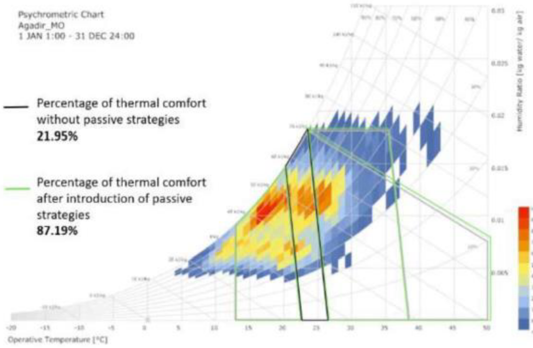

Fig. 07. Psychometric Chart of the city of Agadir

Proposed Solutions:
- Medium openings (20 to 40%)
- Set Openings to West/Southwest and East/Northeast to promote natural ventilation
- Set insulated Roofs

4.3.4 Marrakech:

The temperatures in Marrakesh are characterized by rather strong seasonal and daily temperature variations. The rather dry climate results in large differences between dry bulb and wet bulb temperatures, and so a good potential for evaporative cooling in the summer. Wind speed appears to be generally low, so wind-induced natural ventilation is less likely and natural ventilation has to rely on temperature differences.

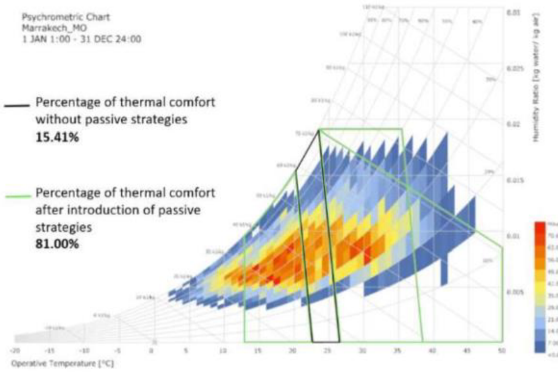

Fig. 08. Psychometric Chart of the city of Marrakech

Proposed Solutions:
- Thick and massive walls, floors and roofs with phase shift time over 8 h
- Medium openings (20 to 40%)
- Set Openings to West/Southwest and East/Northeast to promote natural ventilation
- Passive air conditioning through natural ventilation coupled with high thermal inertia

5 Results:

5.1 Compliance of the results with local regulations:

The Design Explorer tool allows visual highlighting of the results of the simulation scenarios studied. It is also possible to define a threshold for the choice of possibilities already respecting the RTCM. The latter defines the maximum energy consumption per year per m², according to the regions of Morocco:

Table 05. Thermal Performance of Residential buildings per area in kWh/m²/year

Thermal performance of residential buildings by area in kWh/m²/year			Complying results
Z1	Agadir	40	1740
Z2	Driouch	46	7
Z3	Meknes	48	993
Z5	Marrakech	61	585

5.2 Distribution of complying results:

The results for each city are filtered in accordance with minimum thermal performance depending on the

Table 05. Overall look on the results of the filtered results in the 4 climate regions

		SB	SC	AC	AB_EW	AB_NS	AB_GC	S_NS
Agadir	LMI	79,27	79,93	79,93	80,79	79,79	80,95	79,68
	SDA	35,61	72,43	43,18	26,16	25,88	22,40	34,52
	Energy/m².Year	36,22	36,00	32,29	33,72	35,19	29,97	35,47
Driouch	LMI	-	62,51	-	-	-	-	-
	SDA	-	83,38	-	-	-	-	-
	Energy/m².Year	-	41,31	-	-	-	-	-
Marrakech	LMI	70,21	79,69	69,28	70,41	70,70	70,34	70,44
	SDA	16,06	82,24	36,64	15,51	24,67	20,96	16,00
	Energy/m².Year	58,61	49,28	55,41	57,09	55,99	50,21	59,01
Meknes	LMI	76,07	62,27	70,25	78,62	78,84	80,25	74,63
	SDA	25,99	87,78	37,05	19,43	30,65	20,30	22,78
	Energy/m².Year	45,81	25,38	43,91	44,24	42,19	36,73	45,90

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zone in order to make it easier to process the data, as shown in figure 09.

The distribution of the overall results is different depending on which region is analysed. Figures 10-13. Shows this distribution depending on the combinations which comply with the set regulations.

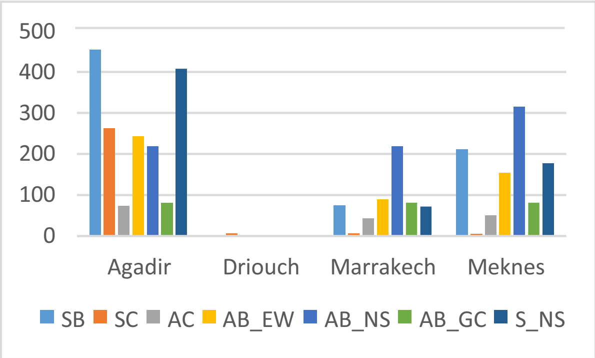

Fig. 09. The number of complying results by typology and regions

6 Discussion:

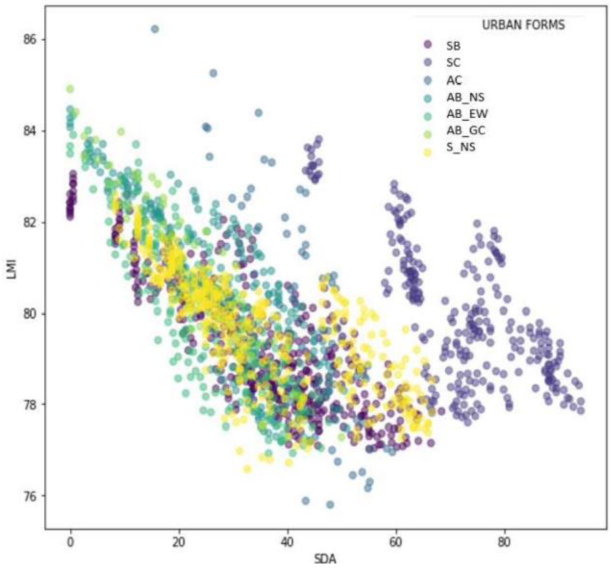

Fig. 10. Scatter Distribution for results in the city of Agadir

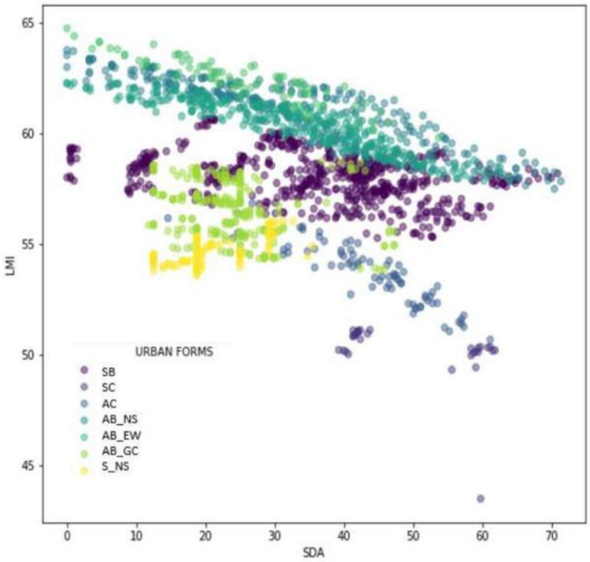

Fig. 11. Scatter Distribution for results in the city of Driouch

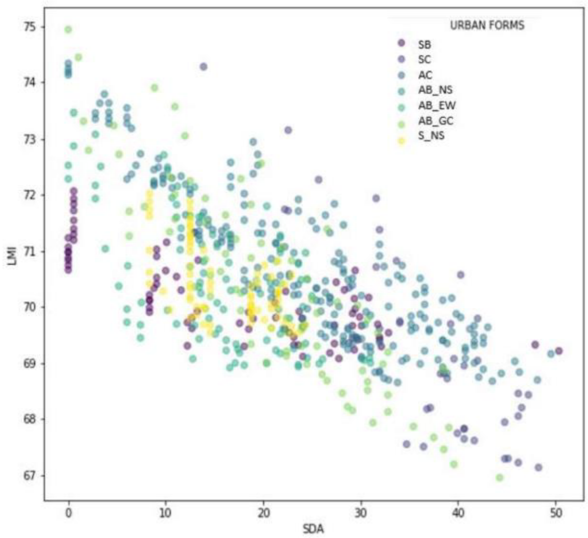

Fig. 12. Scatter Distribution for results in the city of Marrakech

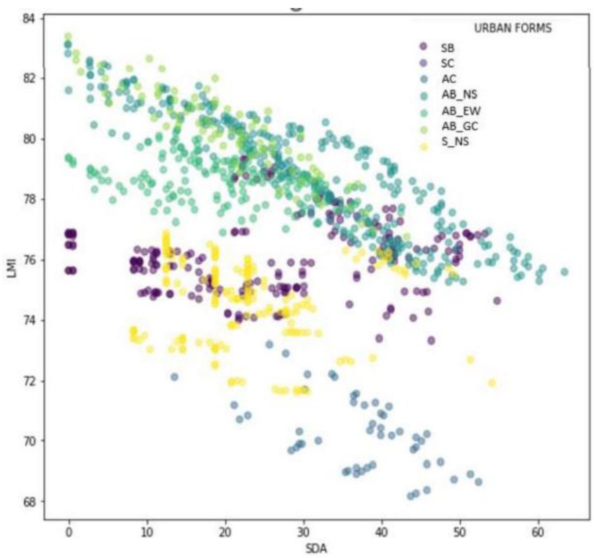

Fig. 13. Scatter Distribution for results in the city of Meknes

6.1 Appropriate urban forms:

6.1.1 Slab oriented West-East:

In all configurations, it is important to avoid setting up the form as a slab oriented in the West-East direction. It is mainly due to the over-exposer of the south side in a dry and hot environment.

6.1.2 Thermal Energy Loads:

The results don't show big differences in the load matching indexes and the annual energy consumption between the different urban forms in the same region which means that the designer could afford the use of any of these forms depending on the overall constraints.

6.1.3 Daylighting:

Regardless of the region, urban forms with included patios favour better daylighting possibilities. Although the results are very important in the initial design phases,

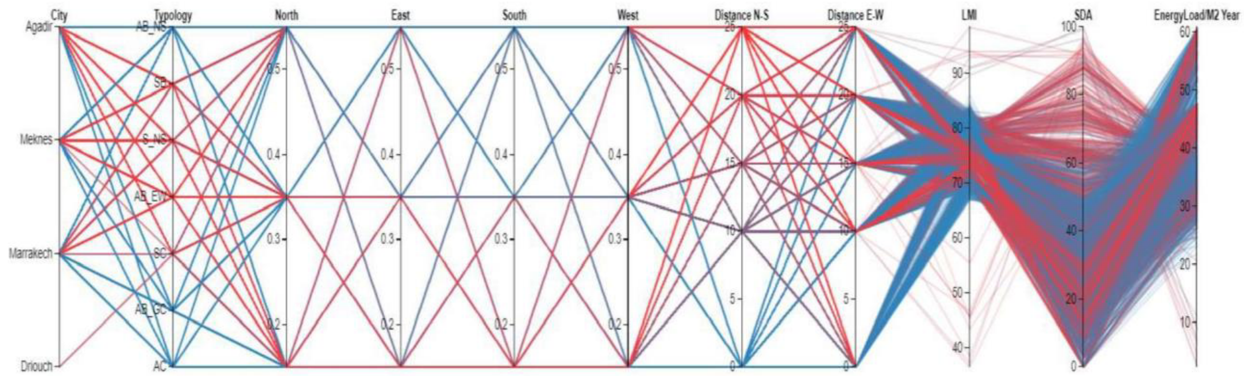

Fig. 14. Selected results in accordance with the National Thermal Regulation for Construction

they stay not conclusive. It is highly recommended to analyse the impact of a distributed parametrised window/wall ratios.

6.1.4 Recommendations:

- <u>Agadir:</u>

The city of Agadir does not present much thermal stress with respect to our study. It is already very visible that the best provisions remain the use of typologies:

- Scattered Courtyard
- Assembled Blocs
- Assembled Blocs East-West

- <u>Driouch:</u>

In the case of the city of Driouch, it is advisable to add patio devices for the building blocks in order to benefit from the best results.

- <u>Marrakech:</u>

For the city of Marrakech, it is very wise to find a balance between the rate of exploitation of the tertiary surface and the use of shade between buildings making up the complex. It is also wise to exploit the use of a patio either local for each block or for the whole complex, in order to maximize the exploitation of natural lighting, while promoting the transport of air for the natural ventilation.

- <u>Meknes:</u>

For the city of Meknes, it is visible that several provisions are still valid but the best ones, maximize natural lighting by using a patio and protecting against the south and south-west orientation, with encouraging results:

- Scattered Courtyard
- Assembled Blocs
- Assembled Blocs East-West

7 Conclusion:

The objective of the article was to create a methodology to be integrated in the design process of social housing neighbourhood. The financial constraints created by the necessity for affordability, make it harder for real estate developers to integrate energy considerations in the design. Therefore, it is essential to concentrate the efforts on passive strategies, which require no additional important investment.

The applications on the 4 regions have indicated the weaknesses and strengths which should be used in the designs of the buildings. Urban forms with bigger exposed surfaces would not be implemented especially if these surfaces are South oriented. The cities of Agadir and Meknes offer more flexibility for the designer in order to yield better results, while Driouch and Marrakech have harder climates.

Nonetheless, the methodology is not in itself conclusive. It must be followed up by further energy simulation and energy production depending on the context.

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