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The Impact of the Application of Energy Efficiency Measures on the Energy Consumption of Residential Building

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Key words: Energy efficiency, thermal building regulations in Morocco, bioclimatic measures, thermal comfort, bioclimatic diagrams, thermal insulation

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Abstract: This study presents the impact of the application of energy efficiency measures on the energy consumption of residential building. In this study, we analyzed the importance of the application of the RTCM and bioclimatic measures located in different climatic contexts. The results showed that the thermal insulation of the building envelope can reduce the energy consumption related to the heating and air conditioning. In addition, according to the results of that study, it was determined that using principles of the bioclimatic architecture and appropriate design strategies are essential to achieve indoor comfort conditions. Investigating and methodological tools were based on the documentation, plans, photos and surveys.

INTRODUCTION

The building sector is considered as one of the most dynamic sectors in Morocco, insofar as it creates wealth and employment and energizes the industrial and mining sectors. This sector plays a major role in the economic and social development of the country with a contribution to the national GDP of almost 7% and to the employment of 9% of the active population. This is justified by the sustained pace of population growth and urbanization. Indeed, Morocco has an urbanization rate of 62%, thus showing a remarkable increase in the urban population and in households.

In addition, the residential and tertiary building sector is the second most energy-intensive sector with 33% of total energy consumption in Morocco and contributes to 11% of GHG emissions.

The energy consumption of the building sector is experiencing a significant acceleration due to the rapid development of the housing stock, estimated at an increase of around 6.4%. Concerning residential which represents 29% of the total energy consumption of the country, it constitutes an important potential deposit in terms of rationalization of energy consumption and energy saving through the adoption of energy efficiency measures and the integration of renewable energies, hence, the need to be part of an energy-saving approach.

Given the energy importance of the building sector and in order to achieve its environmental objectives on a national and international scale, notably those of the Paris agreement, the agenda of the Sustainable Development Goals (SDGs) and from the new Urban Agenda, Morocco has adopted an energy strategy, aiming at an energy saving of12% by 2020 and 15% by 2030 from which the residential sector will contribute 19% and the tertiary sector by 10%[1].

In this sense, a legal arsenal has been put in place, namely law 47-09 relating to energy efficiency with the aim of strengthening the energy performance levels of constructions to be built or renovated, through the

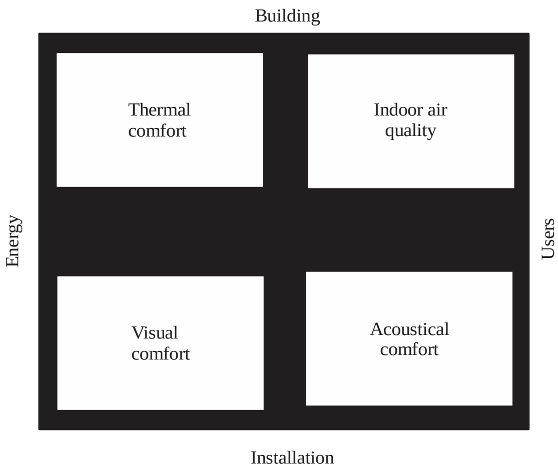

Fig. 1: Design consistent with thermal comfort and energy efficiency

implementation of incentive measures to guarantee a better energy balance of buildings by climatic zones and law 13-09 relating to renewable energies which promotes the production of energy and the use of renewable energy sources in level of buildings and technical equipment.

Progress has been made with the aim of improving thermal comfort and reducing the heating and air conditioning needs of buildings. This process was marked by the adoption of the Thermal Building Regulations in Morocco (RTCM) which aims to produce a new generation of constructions meeting minimum energy efficiency requirements according to climatic zones. This approach has been consolidated by the production of new standards in terms of sustainability and energy efficiency in buildings.

Thermal comfort: Thermal comfort is one of the components of what is called the “indoor environment”, the others are air quality, lighting and acoustics[2].

Thermal comfort is defined as a state of satisfaction with regard to the thermal environment. It is a complex subjective concept that is highly interdisciplinary and involves various phenomena. Consequently, the evaluation methods are different depending on the aspects we are interested in.

Thermal comfort can be defined as a sensation produced by a system of physical, psychological, physiological factors, leading the individual to express the well- being of his state. Thermal comfort can be characterized in several ways:

- The absence of complaints for discomfort (Fanger)
- Lack of general well-being
- Conditions for which the body’s self-regulatory mechanisms are at a minimum level of activity (Givoni)

The study of thermal comfort is very important not only for the quality of the interior atmospheres but also for the quantity of energy to be provided by the equipment (Fig. 1). Normative references of thermal comfort[3]:

- ISO 7730: Analytical determination and interpretation of thermal comfort by calculating the PMV and PPD indices and by local thermal comfort criteria
- ISO 10551: Assessment of the influence of the thermal environment using subjective judgment scales
- ASHRAE 55 standard: which defines comfort as a condition of mind which expresses satisfaction with the thermal environment and is evaluated by a subjective evaluation

Several evaluation methods and combinations have been developed by the researchers, based on experiments carried out for the simultaneous manipulation of the variables of thermal comfort Among these methods, we can cite:

- Value of PMV and PPD
- Effective temperature resulting temperature
- Equatorial comfort index
- Thermal stress index
- Operating temperature
- BRS method
- Bioclimatic diagrams (Givoni, Olgyay, Mahoney, etc.)

The ISO 7730 standard introduces two indices for the evaluation of the thermal comfort of the occupants[4]:

The PMV (Predicted Mean Vote) index which represents the preference of individuals expressed as a function of the difference between the production of metabolic heat and the dissipation of heat in the room under given temperature and clothing. It allows to predict the average vote of a group of people on a graduated scale while expressing their thermal sensation. It is calculated as follows:

$$PMV =_{e-} \left(0.303.+0.028\right)\times L\exp\left(-0.036.\,M\right)$$

The PPD: index of the Predicted Percentage of Dissatisfied (PPD) is an index which establishes a quantitative prediction of the percentage of dissatisfied people thermally determined from the PMV. The PPD index is expressed as a function of the relationship:

$$PPD = 100.95e^{-\left(0.3353.PMV^4+0.2179PMV^2\right)}$$

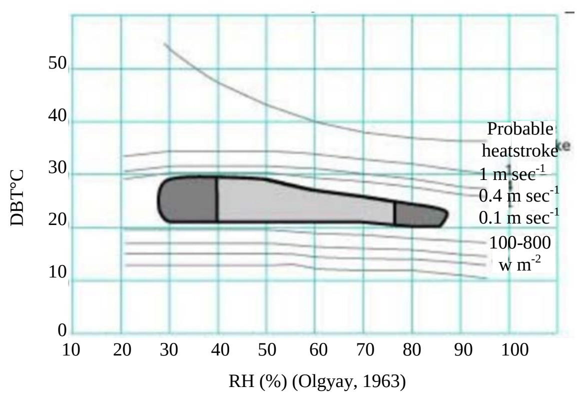

Fig. 2: Givoni diagram

Bioclimatic analysis methods: Bioclimatic diagrams are tools for climate analysis and synthesis that allow you to choose the main architectural options based on the requirements of thermal comfort and climate profiles.

The principle consists in comparing on a single graph, "a polygon of comfort", representing the external conditions and the area of thermal and hygrometric influence of certain architectural solutions or certain devices. This makes it possible to predict the human comfort zone and to deduce the means of intervention by architectural or technical devices which can restore the zone of thermal satisfaction[5]. The diagram of Olgyay Givoni:

According to Givoni. B: "This method is based on a" bioclimatic diagram" showing the human comfort zone in relation to ambient air temperature and humidity, average radiant temperature, wind speed, solar radiation and evaporative heat loss"[6].

The method assumes that thermal comfort cannot be estimated from the only parameter that is the air temperature but involves several factors such as humidity and air speed. Given the diversity of thermal comfort variables, there are a number of equations developed to obtain the temperature of neutrality T_n (Fig. 2).

According to Humphreys in a simplified way, a felt comfort temperature is called "operative temperature" or "resulting dry temperature"[7]:

$$T_{operative} = \frac{(T_{air} + T_{wall})}{2}$$

The "Resulting dry Temperature" (Tr) or "Global Temperature" often noted Tg which reflects the comfort felt is defined as the weighted average of the air temperature and the average radiant temperature. This temperature is one of the important factors that determine comfort. It is given by[8]:

$$T_r = \left(\frac{h_c \times T_a + h_r \times T_{mr}}{(h_c + h_r)}\right)$$

Where:

T_a : Dry temperature measured by an ordinary thermometer placed in the shade
T_{mr} : Wall temperature or mean radiant temperature
h_c : Convection transfer coefficient expressed in W/ m^2 K
h_r : Radiation transfer coefficient expressed in W/ m^2 K

Thermal comfort in Morocco: Given the regional differences marked by the 6 climatic zones in Morocco, two strategies are to be adopted according to the needs:

- Winter comfort responds to the strategy of heat which consists of capturing solar energy and storing it in the mass keep by insulation and distribute it in the building
- The comfort of summer responds to the cold strategy which consists of protecting from the sun's rays, minimizing internal heat, dissipating excess heat and cooling naturally

Application of the RTCM prescriptive approach: The regulation adopts the use of two approaches: the prescriptive approach and the performance approach. The prescriptive approach consists of imposing a minimum thickness of insulation on the walls, roof, floor and glazing. Whereas the performance approach consists in verifying that the projected annual thermal transfers of the building are below a threshold defined by the regulations.

The demonstrator projects integrating the energy efficiency standards covered by the Thermal Construction Regulations in Morocco (RTCM) were carried out as part of the National Program for Energy Efficiency in Buildings funded by the EU.

The projects selected for analysis as part of this research represent a variety of construction types (economic housing, social housing, villas) located in different climatic zones. The energy efficiency measures adopted in the context of these projects mainly relate to the installation of good insulation and the installation of double glazing and solar water heaters (Fig. 3 and Table 1).

The obtained results: Regarding the demonstrator projects, the architecture and the functional characteristics were already fixed. The energy efficiency measures implemented on the envelope meet the requirements of the prescriptive approach to thermal regulation. This approach fixes the thicknesses of the insulators and the

Table 1: Application of demonstrative projects

Projects	Location	Climatic zone
Jacaranda social housing	Tamansourt, Marrakech, Tensift Al Haouz Province	Z5
AL Ourod2 social housing	Urban municipality of El Aroui, Province of Nador	Z3
Al Karama		
Social housing	El Hajeb, Province of Meknes	Z4
Fal El Hanaa economic housing	Aïn Sebaâ, Casablanca 637 economic housing	Z1

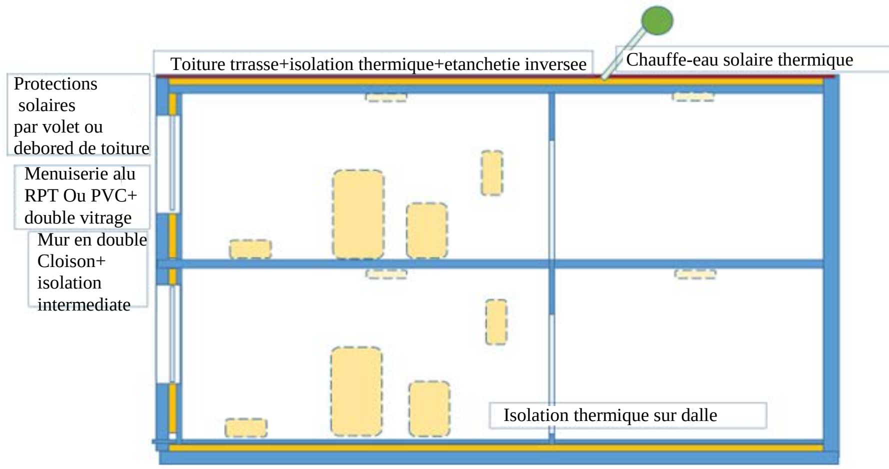

Fig. 3: Application points for demonstrator projects

minimum characteristics of glazed joinery but does not impose any prescription in terms of urban and architectural design making it possible to improve climatic comfort by static solutions.

The diagram below concerns the analysis of the impact of the parameters of the building envelope on the annual heating and air conditioning needs of the building under standard conditions of use and in different climatic zones. Theoretical energy needs are estimated per dwelling were deducted from heat transfers taking into account an average coefficient of the equipment used for the production of cold or heat inside the housing necessary to compensate for these heat transfers. The simulations were carried out using design builder software on Jacaranda projects by Tamansourt, Alkarama by El Hajeb and AL Ourod by Al Arroui. As for the El FAL project by Ain Sebaa, the simulations were carried out using TRNSYS Software[9].

The implementation of energy efficiency measures on demonstrator projects made it possible to significantly reduce heat transfers. This reduction is noted through a significant reduction in the proportionally greater electrical needs for heating.

The air conditioning requirements remain at a high level, even after the implementation of thermal regulations which calls for the introduction of bioclimatic solutions.

Thus, the prescriptive measures on the quality of the insulation of the envelope improve winter comfort by eliminating in particular the cold radiation of the opaque and glass walls but they have a more limited impact on summer comfort because they do not propose provisions for the evacuation of the heat confined in a natural way in particular ventilation, the use of the inertia of the building, adjustment of the size of the openings according to the orientations.

The application of RTCM improves the thermal performance of buildings and achieves attractive energy savings. The performance approach and by means of thermal simulation can make it possible to optimize town planning and architectural arrangements from the design stage.

Application case of the bioclimatic approach: This research highlights good practices in energy control and adaptation of buildings to the climate through the use of the principles of passive architecture and bioclimatic architecture for the case of 3 types of housing located in 3 different climatic contexts (Fig. 4).

The envelope of a building is the surface that separates the interior volume of the building from the exterior environment. It is around this envelope that heat exchanges operate which will influence the building's heating or cooling needs (Fig. 5).

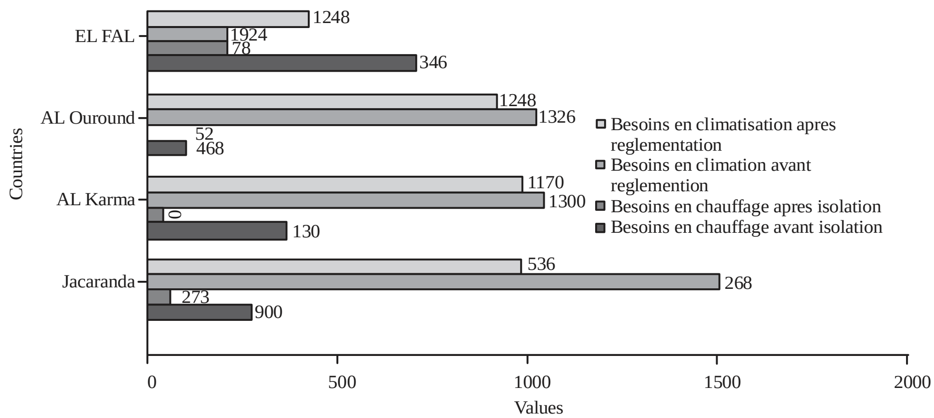

Fig. 4: Comparaison entre besoins energetiques des projets demonstrateurs avant et apres reglementation

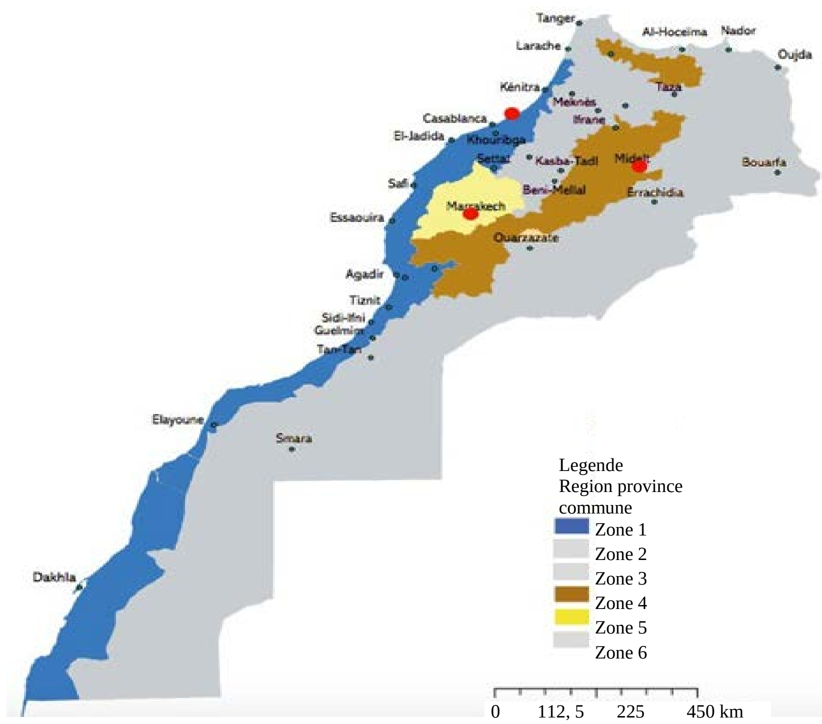

Fig. 5: Climate zoning map in Marocco

The envelope plays a key role in determining the levels of thermal, visual, acoustic and olfactory comfort. Thus, it is a major element in improving the energy efficiency of buildings, both new and existing.

The envelope is made up of several elements such as walls, openings, low floor, high floor and optional sun protection. The parameters of the envelope are linked to the constructive elements of the latter.

The 3 different types of housing studied as part of this work are part of a study "Architecture and energy efficiency" around cases of good practice of energy efficiency in Morocco[10]. This catalog produced by the National School of Architecture supported by GIZ highlights relevant cases of buildings taking into account best practices in terms of energy efficiency and integration of renewable energies. The buildings analyzed as part of this study are:

- A villa in Marrakech
- A modern Moroccan house in Midelt
- A high standing apartment in Rabat

Table 2: The exterior walls of the Marrakech villa

Materials	Thicknesses (cm)	Thermal transmission coefficient U (W/M2.K)	Regulatory requirements of the RTCM for climatic zone 5 (Marrakech)
Plaster	1.0	0.24	
Concrete block	15	The value of U is less than the regulatory	16-25%≤0.7
Glass wool	1.0	limit requirements set by the RTCM	26-35%≤0.6
Terracotta brick	15		
Cement mortar	1.5		

Table 3: The components of the roof of the City Marrakech

Materials	Thicknesses (cm)	Thermal transmission coefficient U (W/M2.K)	Regulatory requirements of the RTCM for climatic zone 5 (Marrakech)
Floor tile	2	0.38	16-25% =≤0.65
Cement mortar	6	The value of U is less than the regulatory	26-35% =≤0.55
Polyurethane foam	6	limit requirements set by the RTCM	
Reinforced concrete	5		
Weighed down	16		
Plaster	1		

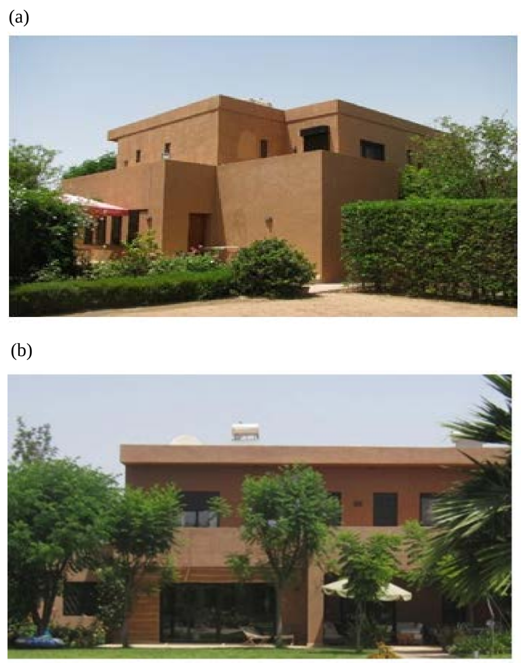

Fig. 6: Villa Marrakech

Case of the city of Marrakech:
Description: A building of slender design oriented east-west, so that, its large dimensions are facing South. It is a villa located in the suburbs of Marrakech. It is built on a floor area of 168.63 m^2.The villa combines the ability to store the heat of the sun, through the South-facing openings and the ability to regulate the ambient temperature thanks to its high thermal inertia (Fig. 6 and Table 2, 3).

Midelt city case[11]:
Description of the building: The Modern Moroccan house is the most widely used and built type in Morocco.

Fig. 7: Moroccan house in Midelt

This “modern Moroccan house” residential building built on ground floor = 2 has a compactness and an adequate orientation. The first main facade is oriented to the South, the openings on the first and second floors benefit from solar gain allowing significant heat and natural lighting. The integration of the building’s thermal insulation is the energy improvement item to be considered as a priority in order to massively reduce the heating and air conditioning needs (Fig. 7 and Table 4, 5)[12].

Case of the city by Rabat[13]
Description: This project “Les terrasses El Menzeh” consists of 6 buildings arranged in three blocks with 72

Table 4: The components of the exterior walls of a modern Moroccan house in Midelt

Materials	Thicknesses (cm)	Thermal transmission coefficient U (W/M2.K)	Regulatory requirements of the RTCM for climatic zone 4 (Marrakech)
Plaster	2	0.45	16-25%≤0.6
Brick 6	7	The value of U is less than the regulatory	26-35%≤.6
Glass wool	5	limit requirements set by the RTCM	
Air	4		
Brick 8	10		
Mortar	2		

Table 5: The components of the roof of a modern Moroccan house in Midelt

Materials	Thicknesses (cm)	Thermal transmission coefficient U (W/M2.K)	Regulatory requirements of the RTCM for climatic zone 4 (Marrakech)
Ceramic tiles	2	0.44	16-25%≤0.55
Mortar	2	The value of U is less than the regulatory	26-35%≤0.49
Concrete slope form	8	limit requirements set by the RTCM	
Prestressed concrete	5		
Hollow concrete block	16		
Glass wool	5		
Air	13		
Plaster	2		

Table 6: The components of the exterior walls of the El Menzeh terraces project

Layers	Thicknesses (cm)	Thermal transmission coefficient U (W/M2.K)	Regulatory requirements of the RTCM for climatic zone 1 (Rabat)
Mortar	2.5	2.08	16-25%≤1.2
Brick	10		26-35%≤1.2
Air blade	9		
Brick	7		
Mortar	1.5		

Table 7: The components of the roof of the "El Menzeh terraces" project

Layers	Thicknesses (cm)	Thermal transmission coefficient U (W/M2.K)	Regulatory requirements of the RTCM for climatic zone 1 (Rabat)
Ceramic	0.5	0.53	16-25%≤0.65
Mortar	2		26-35%≤0.65
Perlite	2		
Full concrete	4		
Elastomer foam	2.5		
Concrete	5		
Concrete block	20		
Mortar	1, 5		

apartments enjoying a good orientation for optimal sunshine in all the rooms of the double L-shaped facade. The project is designed with landscaped interior patios and large bay windows overlooking terraces. The concept adopted makes it possible to minimize and reduce electricity consumption while opting for double glazing (Fig. 8 and Table 6, 7).

BIOCLIMATIC DIAGRAMS

The bioclimatic diagrams of Givoni and Szokolay are tools to aid in the overall decision of the project, making it possible to establish the degree of necessity of implementing certain options such as thermal inertia, generalized ventilation, evaporative cooling, then heating or air conditioning (Table 8).

ASSESSMENT OF THE APPLICATION OF BIOCLIMATIC MEASURES

The most important design parameters affecting indoor thermal comfort and energy conservation on a building scale relate mainly to the orientation, shape, layout of rooms, building materials and thermo-physical properties of the building envelope. These parameters permanently affect the heat transfer coefficient (U value) of the building.

Orientation of the building and openings (windows): Regarding the case of Marrakech, the south facing walls of the villa have a large glass surface, especially, on the first floor. The villa has a maximum on the South facade, a minimum on the west facade, a moderate number on the

Table 8: Discription about market in Midelt and Reset

Recommendations according to Givoni Szokolay bioclimaticdiagrams for the city of Marrakech	Recommendations according to the Givoni Szokolay bioclimatic diagrams for the city of Midelt	Recommendations according to bioclimatic diagrams for the city of Rabat Givoni/Szokolay
It is recommended to opt for natural ventilation with dehumidification, especially for the month of September and to have a high thermal inertia natural ventilation during the summer season	It is important to opt for an active heating system throughout the winter season	It is necessary to opt for an active heating system during the cold months (November December, January and February) and during with the night for part of the months of March April and
The use of night ventilation at night will limit the use of artificial air conditioning during the 3 months of summer	It is not necessary to air condition in July and August with sufficient thermal inertia	
The diagram also shows that one can obtain a comfortable indoor climate by using passive heating thanks to internal gains during the months of October, April and May	It is recommended to use internal inputs as passive heating during spring and autumn	It is not necessary to air condition in July and August with sufficient thermal inertia It is important to use the internal inputs as passive heating during the day for the months of March and April
Active heating should be used for the winter season and fairly cold months like November and March		

(a) (b)

Fig. 8: El Menzech terrace project

East and North facades. A shading device overlooks the South facade of the 2nd floor. This device was designed to completely hide the bay windows during the summer while these glass surfaces are fully sunny during the winter.

Since, windows are important parts of the building envelope that have a significant effect on energy performance and thermal comfort, they should be chosen with care. In building envelopes, windows are an important source of heat loss outside and solar gain inside. Double glazed windows offer more thermal resistance in cold (Midelt) and hot (Marrakech) climates.

Walls and roof: The materials combined and placed in close position with mortar constitute the method of construction of the masonry. By introducing insulating materials, energy consumption is reduced through the building envelope. Heavy walls and roofs will help protect the building from heating from solar penetration.

Analysis of the impact of the application of energy efficiency measures: The diagram below shows the difference resulting from the comparison between the regulatory heat transfer value U and U obtained for the envelopes of buildings in different climatic zones. Appropriate levels of insulation would make it possible to comply with thermal regulations and considerably save the energy consumption of buildings.

The development of energy efficient buildings is conditioned by the adaptation to local climates and the taking into account of the parameters influencing the thermal of the building in the design of the habitat, especially, in dry or tropical environment where climatic changes are strongly noted (Fig. 9 and 10). This approach leads to guidelines and recommendations for improving thermal comfort and reducing the climatic load of the premises.

This analysis highlights the effectiveness and relevance of the adoption of the measures adopted, namely the insulation of the roof, the insulation of the exterior walls, the installation of double-glazed joinery. This is justified by the calculation of the difference in regulatory thermal transmission U compared to U obtained according to RTCM for each of the projects located in different climatic contexts. The energy performance of housing depends both on the intrinsic characteristics of the housing, the type of buildings, climatic conditions, topographical locations, etc.

According to this analysis, it seems that the impact of each solution depends mainly on the climatic zone and the type of habitat (design and layout of spaces, glazing rate). Indeed the difference in terms of thermal transmission obtained following solution 1 relating to the insulation of exterior walls is greater and more particularly for EL FAL Casablanca projects where the insulation of the walls is

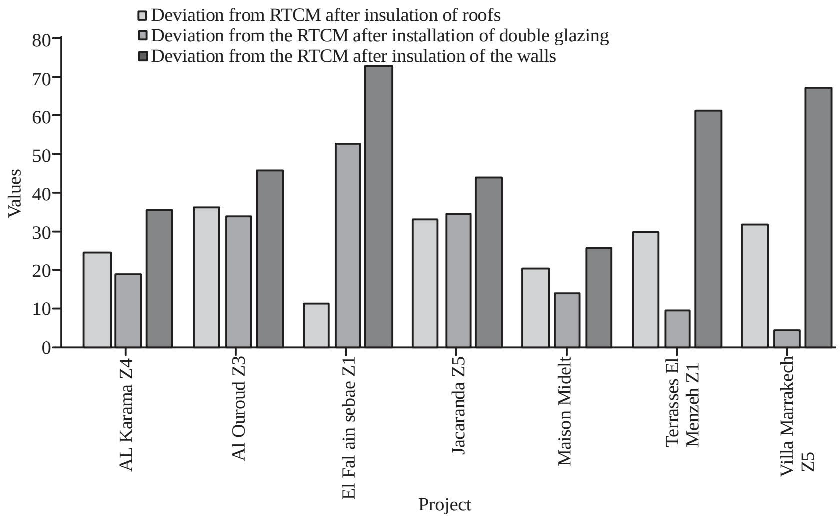

Fig. 9: Comparison between thermal transmission of exterior walls roofing and glazing of projects before and after insulation

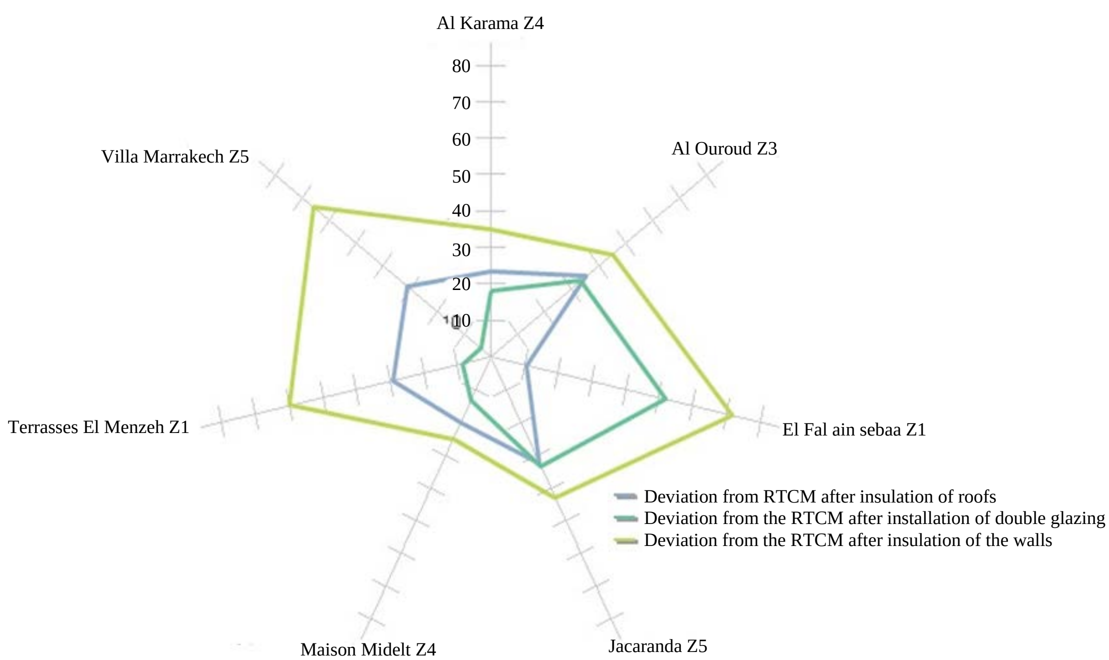

Fig. 10: Comparison between the thermal transmission gap following the application of RTCM

done from the inside and from the outside. The walls represent the largest area of heat loss, their insulation therefore constitutes a relevant energy improvement potential.

For all types of housing combined, the insulation of the roof is necessary for hot and cold climates, it can also considerably reduce the energy needs of buildings.

Since, windows are important parts of the building envelope with a significant effect on the energy performance of buildings, it is necessary to opt for double glazed windows offering more thermal resistance in cold climates. However, for medium standing accommodation and Villa with TGBV exceeding 25%, double glazing generates summer overheating, if it is not protected from direct solar radiation.

Regarding the case of Marrakech, the south facing walls of the villa have a large glass surface, especially on the first floor. The villa has a maximum on the South

Table 9: Total variance explained

	Initial Eigenvalues			Extraction sums of aquared loadings			Rotation sums of squared loadings		
Components	Total	Variance of (%)	Cumulative (%)	Total	Variance of (%)	Cumulative (%)	Total	Variance of (%)	Cumulative (%)
1	1.524	50.816	50.816	1.524	50.816	50.816	1.392	46.395	46.395
2	0.882	29.410	80.226	0.882	29.410	80.226	1.015	33.831	80.226
3	0.593	19.774	100.000						

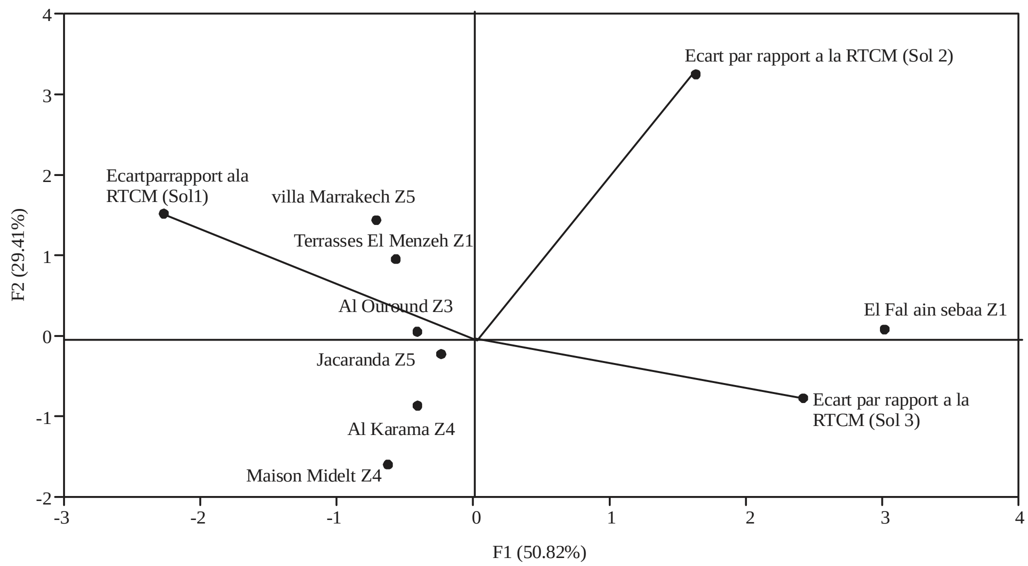

Fig. 12: Graphical representation of energy efficiency solutions and projects according to the Factor plan (F1, F2)

facade, a minimum on the west facade, a moderate number on the east and north facades (summer ventilation). A shading device overlooks the south facade of the 2nd floor. This device was designed to completely hide the bay windows during the summer while these glass surfaces are fully sunny during the winter.

Principal component analysis and classification of the insulation solutions used: To classify the projects according to the isolation solutions, we will proceed to a factorial analysis which is a multivariate technique called interdependence by carrying out a Principal Component Analysis (PCA)[13] by taking the isolation solutions as variables and projects as individuals.

This analysis will allow us to identify the factorial axes which synthesize the solutions studied in a limited number while preserving the initial information, taking into account the interactions which can exist between the solutions of isolation. All the results obtained come from the software SPSS[14]. After validating the PCA analysis, the results obtained are summarized in.

We see from the table that the factor has an eigenvalue of 1.5 that is to say that it carries a quantity of information, it explains 50.16% of the total information presented in the graph.

The second is less informative with a quantity 0.88 or almost 29.41% of the total information contained in the table thus the first two axes mentioned explaining 80.22% of the total variance (Table 9).

Analysis of the factorial plane (F1, F2): The factorial axes are virtual axes resulting from a synthesis between the variables of the analysis. The proximity of two projects in the factorial plane means that these two projects have a similar behavior towards the set of variables in fact according to the Factorial plane F1 and F2 we can build 4 homogeneous groups of projects according to their degrees performance. Classification by groups:

- 1st Group: C1 = EL FAL Ain CASABLANCA.
- 2nd Group: C2 = Villa Marrakech, El Menzeh Terraces Project. 3rd Group = Al Ouroud project, JACARANDA Project
- 4th Group = Moroccan house in Midelt, AL Karama Project

The observations to be drawn: The factorial axes are virtual axes resulting from a synthesis between the variables of the analysis (Fig. 11).

The most interesting points are generally those which are fairly close to one of the axes. These points are well correlated with this axis and are the explanatory points for the axis. In the mapping above, we can clearly see that EL Fal Casablanca is extremely correlated with the horizontal axis.

The proximity between El Fal Casablanca project and the difference obtained following the installation of double glazing underlines a strong correlation between the two. Likewise, a strong correlation is observed between the difference obtained following the insulation of the roof and the projects: Villa Marrakech and Terraces El Menzeh.

CONCLUSION

From this analysis, we conclude that for all the projects, the energy efficiency measures (thermal insulation) or bioclimatic measures (orientation, shape) implemented have improved the thermal performance of buildings and obtain thermal comfort justified by compliance with the RTCM. Based on the bioclimatic diagrams, we can deduce the solutions recommended for each climatic zone.

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