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Energy Performances of a Passive Building in Marrakech: Parametric Study

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Abstract

This paper deals with the modeling of a villa type house located in the Marrakech (Morocco) suburb. The house is constituted of two floors and was designed to be energy efficient by integrating some passive techniques: overhangs, an Earth-to-Air Heat Exchanger (EAHX), thermal insulation of the roof and external walls. Most of these systems are unusual in Marrakech buildings; thus the objective of this work is to study their effects on the house cooling and heating loads. The modeling of the house is a multi-zone one and it was carried out during one year. The effects of the passive systems on air temperature in the building, as well as on its cooling/heating load, are analyzed through the modeling of 5 cases. The first case is the real house and the others correspond to the lack of one of the system (i.e. the overhang along the south facade in the second floor, thermal insulation of the roof and thermal insulation of external walls), the fifth case correspond to the lack of all the systems ("standard house"). The results show that some of these systems reduce the maximum temperature, while some others act only on the minimum temperature by increasing it. The first systems reduce the cooling load and are very efficient in summer (this is the case, especially, of the thermal insulation of the roof). The other systems reduce the heating load and have a small effect on the cooling load. It should be mentioned that the heating load of the real house is negligible compared to the cooling one. One of the interesting results is that, corresponding to the effect of thermal insulation of external walls. This insulation has a small beneficial effect on the heating load while it increases the cooling load.

Keywords: Cooling Load; Heating Load; Passive Systems; Building; transient multi-zone modeling, insulation, overhang.

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1. Introduction

In Morocco, the operating power cost of air conditioning systems for buildings may account for more than 40% of the total power bill. Furthermore, the impact of air conditioners usage on electricity demand is an important problem as peak electricity load increases continuously, forcing the National Electricity Authority (www.one.org.ma) to build additional plants. In parallel, serious environmental problems are associated with the use of air conditioning [1].

In the Moroccan traditional way of life, people developed empirical solutions (architectural, but also behavioral) to reach a minimal level of thermal comfort. However the rapid growth of income induces higher comfort requirements, which is mostly achieved through the use of electric air-conditioning equipment. This leads to a significant increase in energy consumption and in greenhouse gas emission. However, it is often possible to fulfill thermal comfort requirements at low energy cost, taking advantage of the particular climate features by an appropriate design of the building [2]. Some of the design features that are desirable for energy savings are the same for cold and hot seasons. However, this is not the case for other features like openings, shading devices, etc. The problem of taking advantage of winter solar radiation, while keeping the cooling load to a reduced value is thus a key issue for Mediterranean buildings [3]. It is evident, for example, that an insulated building envelope helps in reducing heating load. Nevertheless, the outdoor night temperature in summer is often lower than the required indoor temperature. Thus, un-insulated walls allow for the evacuation of the heat stored in the building during the day, leading to the reduction of air-conditioning need [4-5].

For the Mediterranean climate, an efficient solar protection should allow for minimizing cooling and heating loads. This means that the shadowed portion of the glazed area should be as large as possible in summer and as low as possible in winter.

Breesch et al. [6] conducted an experimental and theoretical study for the evaluation of the overall thermal comfort of a two floors office building in Kortrijk (Belgium) equipped with two passive cooling techniques: natural night ventilation and Earth-to-Air-Heat-Exchanger (EAHX). These two systems are automatically controlled to meet comfort requirements at different climatic loads. Moreover, the cooling load of the building is reduced by other passive techniques (concrete ceiling with a high thermal capacity, controllable external sunblind on the glazed South-facing facade, presence detection and daylight control). By daytime, the EAHX pre-cools supplied airflow and by night, cool outside air enters the office floors through bottom hung windows located near the ceiling in the offices on the North side. TRNSYS [7] simulations were used by the authors to evaluate the relative performance of these techniques. The authors concluded that night ventilation is the most efficient technique. Indeed, night natural ventilation is one of the interesting passive techniques in hot and moderate climates with large diurnal temperature difference over the summer, which is the case of Marrakech climate [6,8]. Soutullo et al. [9] conducted an experimental and theoretical study on many passive systems implemented in four buildings in different climatic zones in Spain (continental, desertic, ocean and extreme continental). The systems include thermal insulation, shading of the roof, natural ventilation induced by solar chimneys, ventilated shadowed roofs, double glazing, thermal bridge breaking, shading porch (overhang) at south façade. The buildings are office ones and some of them are new constructions; while others are refurbished. The design of the buildings was conducted by means of the 'Givoni Chart' tool [10-11]. Moreover, the buildings are monitored to evaluate experimentally the savings in energy induced by the integrated passive systems. A TRNSYS modelling was also conducted and the authors calculate the savings due to bioclimatic strategies by comparing the final building energy demands from the simulation, to the reference values from experience. Raeissi et al. [12] conducted a transient mono-zone numerical simulation to evaluate the reduction in the cooling load of a house by three different roof options: shaded roof, pond (layer of water on the roof) and shaded pond in Shiraz, Iran. The authors claimed that these options achieve a reduction of 43%, 58% and 79% respectively.

The motivation of the present study is to evaluate the performance of the considered passive techniques in Marrakech climate, by means of a transient multi-zone simulation [7].

2. Building description

The building is a villa type one with a floor area of 167m² and 117m² respectively for the 1st and the 2nd floor. The external walls as well as the roof are insulated. The composition of these walls and the roof is given in Tables 1-2. The 1st floor slab composition is similar to that of the roof without insulation. The South facing walls present a significant glazed area, especially in the 1st roof (Table 3).

Standard values for thermal properties were considered [7]. This yields to thermal resistances of 2.67m².K.W^{-1} for the roof, 2.37 m².K.W^{-1} for the 1st floor slab and 2.55 m².K.W^{-1} for the external walls. A 1.20m shading device overhangs the South facade of the 2nd floor. This device was designed to completely shadow the glazed French windows in the summer solstice while these glazed areas are completely sunlit in the winter solstice. There are neither other buildings nor trees in the near surroundings of the building which may shade it.

Table 1: External walls constituents and properties

Material	Plaster	Concrete block	Glass wool	Earthenware brick	Cement mortar
Thickness (cm)	1	15	10	15	1.5
Thermal capacity (kJ.kg^{-1}.K^{-1})	0.88	0.51	0.84	0.9	89
Thermal conductivity (W.m^{-1}.K^{-1})	0.097	0.18	0.039	0.319	0.32
Density (kg.m^{-3})	800	1300	12	1900	200

Table 2: Roof constituents and properties

Material	Ceramic tile	Cement mortar	Polystyrene	Pre-stressed concrete	*Hourdi*	Plaster
Thickness (cm)	2	6	6	5	16	1
Thermal capacity (kJ.kg^{-1}.K^{-1})	0.7	89	0.48	0.92	0.65	0.88
Thermal conductivity (W.m^{-1}.K^{-1})	1.702	0.32	0.03	1.755	1.23	0.097
Density (kg.m^{-3})	2300	200	35	2300	1300	800

Table 3: Glazed surfaces.

Walls	1st floor				2nd floor			
	West	East	South	North	West	East	South	North
Glazed surface (GS) m²	2.94	3.48	26.52	7.62	0.72	2.04	10.43	5.04
Total surface of the facade (SF) m²	45.22	45.22	72.90	72.90	32.13	32.13	56.03	56.03
% of glazed surface (GS/SF)	7%	8%	36%	10%	2%	6%	19%	9%

3. Building modeling

The considered building is located in the suburb of Marrakech, Morocco (31.37°N; 8.2°E and 440m of altitude). The modeling of the building was done in real climatic conditions with hourly measured data during 2009 (temperature, humidity, global solar radiation, wind velocity and direction). Table 4 presents some of Marrakech climate characteristics in 2009. It is noticed that the minimal temperature occurs during January (-1.8°C) even that this month is sunny compared to December. During February and December, the minimum air temperature approaches 0°C. The coldest months are January, February and December. On the other hand, the maximal temperature occurs during July, which is the sunniest month in 2009. Marrakech weather in 2009, began to be hot starting from March. Indeed air mean temperature increases suddenly by 3.5°C in this month compared to February. The hottest months in 2009 are April-August. During these five months air mean temperature increases by about 4°C each month, while it decreases suddenly by 4.9°C in September. It is important to notice the great oscillation of temperature, which is a characteristic of Marrakech climate. The amplitude of these oscillations may reach 29.5°C (in July). The minimum of this amplitude is 23.2°C, which occurs in three months (January, February and September). Table 4 shows that the daily mean solar radiation varies from 2.76 $kW.m^{-2}$/day to 6.92 $kW.m^{-2}$/day.

Table 4: measured meteorological data for Marrakech in 2009 [Agdal Station]

Month	Maximal Temperature (°C)	Minimal Temperature (°C)	Mean Temperature (°C)	Global solar radiation on a horizontal surface ($W.m^{-2}$)	Daily Mean global solar radiation on a horizontal surface ($kW.m^{-2}$/day)
January	21.4	-1.8	8.6	92 865	3.00
February	25.0	1.8	11.8	104 533	3.73
March	30.9	4.4	15.3	138 217	4.61
April	33.9	4.8	16.4	188 940	6.09
May	34.7	8.2	20.7	205 253	6.62
June	40.9	12.0	24.5	198 168	6.61
July	44.0	14.5	28.7	214 418	6.92
August	42.5	15.8	27.0	204 767	6.61
September	36.0	11.4	21.9	158 082	5.27
October	34.6	11.4	21.3	138 406	4.46
November	30.4	4.6	15.8	102 545	3.42
December	24.3	0.8	12.7	85 678	2.76

A transient multi-zone thermal simulation model is applied in the present research for modeling the building. Two zones were considered: zone 1 is the 1st floor and zone 2 is the 2nd floor.

As the objective of this paper is to evaluate the performances of the passive techniques integrated into the building (the overhang, the external walls and roof insulation), simulations were conducted with 5 configurations of the building (Table 5). The first one (#1) is the real house and the fifth (#5) is a '*standard house*' as it is usual in Marrakech residential buildings. Comparisons of temperatures as well as the heating/cooling loads of these cases will allow the determination of the energy performance of each passive technique.

The simulations consist of the hourly calculation of the free running air temperature inside the two zones. These calculations are done using TRNSYS software [7] with the following hypotheses:

- No internal heat generation (the house is unoccupied),
- No blind (existing external blind are considered open all the day),
- The doors and windows are permanently closed,
- No infiltrations,
- Solar absorptivity of the walls and the roof is 0.6.
- Standard heat transfer coefficients are considered.
- Ground coupling is not considered (adiabatic ground floor).

Table 5: Studied configurations of the building

Passive technique	Overhang	Roof insulation	External walls insulation
#1 (real house)	YES	YES	YES
#2	**NO**	YES	YES
#3	YES	**NO**	YES
#4	YES	YES	**NO**
#5 (standard house)	**NO**	**NO**	**NO**

4. Results

Figures 1-2 present the mean free running air temperature inside the two zones of the house for the studied configurations. Air mean temperature is higher than 25°C for nine months (April-December 2009). This temperature is always greater than 18°C even in winter (with negative temperature during the night) and may reach 45°C (#3 in August, 2009). It is noticed that this temperature is always greater than 20°C during the year for all configurations, except for #5 (18.9°C; 18.4°C in January and 19.8; 19.5 in February, respectively in the 1st and 2nd floor), #4 (18.7°C in January and 18.8 in February in the 2nd floor) and #3 (19.7°C in January in the 2nd floor). These values are due to the solar gains through the glazed surfaces and the inertia of the house. Indeed, as shown in Table 3, the walls facing south exhibit a great glazed area (36% and 19% respectively in the 1st and 2nd floor). The significant glazed surfaces of the walls in the 1st floor, explain that the temperature in this floor is always greater than that in the 2nd one.

It should be mentioned that in the real house (#1) the lowest air mean temperature is 20.1°C (which occurs in the 2nd floor during January). A meticulous check of the calculated temperature in January, shows that it oscillates between 19.3°C and 21.5°C in the 2nd floor and between 19.7°C and.23.1°C in the 1st floor. Therefore, it is expected that heating load of the real house will be negligible, as the setting point for heating is 20°C. This will be addressed hereafter.

In order to determine whether studied passive techniques have beneficial effects or not on the cooling/heating loads of the house, we conducted a comparison study of air mean temperature inside the real house (configuration #1) with the other configurations of the building (see Table 5). The comparison between air mean temperature inside the real house (configuration #1) with that of the "*standard house*" (configuration #5) will give further information about the combined effects of the considered three passive techniques. The results of these comparison studies are discussed hereafter.

Comparing configurations #1 and #2 shows that the overhang along the 2nd floor South facing wall, has a significant beneficial effect in the cooling season (March-December 2009), since air mean temperature in #1 is always lower than that corresponding to #2 (without the overhang) in the 2nd floor (Fig. 2). Air mean temperature difference between these two configurations reaches its maximum during December (10.2°C) and its minimum during July (0.5°C). It should be mentioned that the overhang reduces the air mean temperature in the 2nd floor by 0.8°C during June. On the other hand the effect of the overhang along the 2nd floor South facing wall, on the 1st floor air temperature is not negligible. Air mean temperature difference between the house configurations #1 and #2, reaches its maximum during December (6.9°C) and its minimum during April (1.0°C). Finally, the overhang induces an insignificant overheat inside the 1st floor during March (0.4°C).

Comparison between configurations #1 and #3 shows that the roof insulation has a net beneficial effect along the year. Indeed, during heating season (January-February) the roof insulation procures a slight increase in air mean temperature inside both the 1st and 2nd floor. Moreover, this insulation leads to a decrease in this temperature in both floors during cooling season. It is clear from Figs. 1-2 that air mean temperature for #3 (house lacking roof insulation) is the greatest one during April-December, excluded #2 which corresponds to the hottest case inside the two floors in November and December. In summer, the insulation of the roof prevent against overheating in day-time. The reduction in air mean temperature varies from 1.7°C in March to 11.0°C in September. A meticulous examination of air mean temperature reveals that the behavior of the insulation of the roof is particular in February and October. Actually, during February 2009, air mean temperature is slightly increased (from 22.2°C to 22.6°C) by the insulation of the roof in the 1st floor, while this insulation does not affect air temperature in the 2nd floor. During October 2009, roof insulation decreases air mean temperature in the 1st floor (from 41°C to 31.4°C), while it slightly increases this temperature in the 2nd floor (from 30°C to 30.8°C). This behavior is inverted in March 2009. This is probably due to some particularity in the meteorological data of these months.

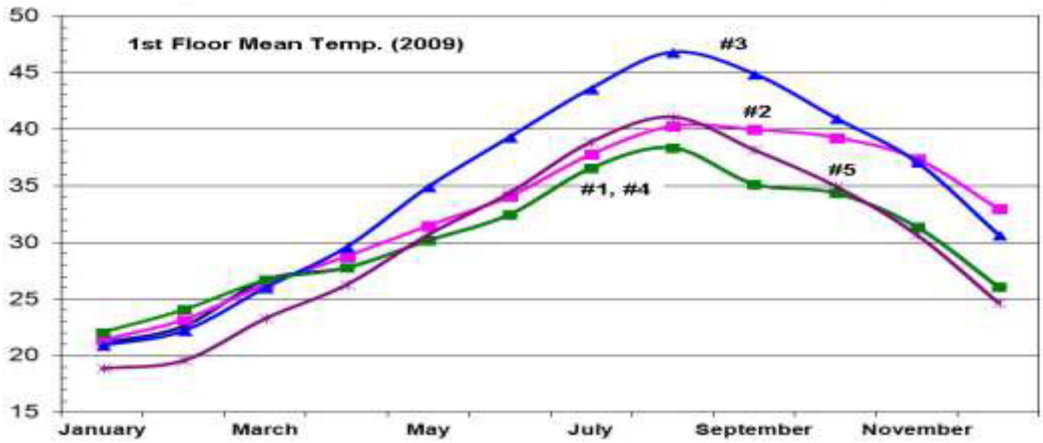

Figure 1: Air mean temperature in the 1st floor

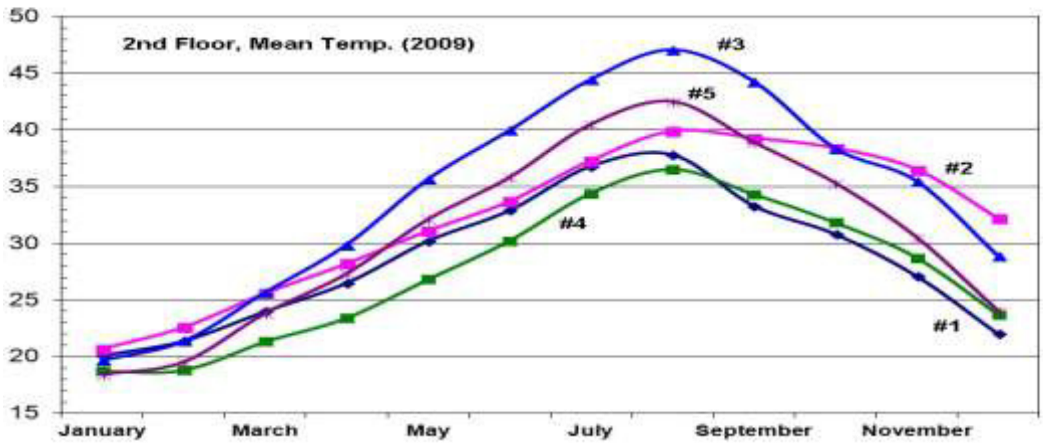

Figure 2: Air mean temperature in the 2d floor

Comparing configurations #1 and #4 shows that air mean temperature is sensibly the same for both configurations. Therefore, the insulation of the external walls has a small effect on this temperature. Precisely, this insulation has a little beneficial effect during the heating season as it increases air mean temperature in the 2nd floor from 18.7°C to 20.1°C in Jan. and from 18.8°C to 21.4°C in Feb. However, its effect on air mean temperature in the 1st floor is negligible. Moreover, the insulation of the walls generates overheating in the 2nd floor during April-August 2009. It is believed that this insulation obstructs night cooling during these months. This behavior has been reported by other authors [4-5]. Thus, one may conclude that external walls insulation is not suitable for Marrakech climate. This issue will be discussed later.

Finally, in order to establish the combined effects of the three studied passive techniques, it is interesting to compare configurations #1 and #5. From Figs 1-2, it can be deduced that air mean temperature in #5 is lower than that in #1 during the heating season. The former is around 18°C-19.6°C, while the latter is around 21-22.6°C. This situation is essentially due to the action of external walls insulation as it was stated above. During the cooling season, air mean temperature in #5 is higher than that in #1, except in the 1st floor at the beginning and the end of the season. The difference between the two temperatures rises starting in May/April, reaches it maximum during September and then decreases and collapse in November/December.

At this stage it is interesting to evaluate the heating and cooling loads of the house. To do so, we have to fix the set points for heating and cooling. In this preliminary study, these are set to 20 and 25°C respectively. Figs 3-4 present heating/cooling loads for the two zones of the house.

Regarding the heating load (negative values in Figs 3-4), it is present during two months (Jan.-Feb. 2009). It is noticed that configurations #4 and #5 exhibit the most significant values, especially in the 2nd floor during January 2009. Remember that these configurations correspond to the lack of external walls insulation. As stated above, this insulation increases air mean temperature inside the house, as it traps solar gains through glazed area. Configuration #3 has a non negligible heating load in the 2nd floor. This is due to heat losses through the roof without thermal insulation.

Cooling load is present during 7 to 10 months depending on the configuration. This load extends from March to December 2009 for configurations #1, #2 and #3; while this duration is reduced to April-November for #5 and May-November for #4. The lack of external walls insulation is responsible of the reduction in cooling load for configurations #4 and #5. Indeed, uninsulated walls permit to the accumulated heat inside the house in daytime to be evacuated through these walls during the night. This action is present at the beginning and the end of the cooling season. As stated above this tendency was also reported by other authors [4-5].

Comparing Figs 3 and 4, one can deduce that cooling load is essentially the same for the two floors except for configurations #3 and #5, in which the insulation of the roof is absent. The lack of this insulation contributes to the huge cooling load in the 2nd floor during May-October 2009.

A meticulous inspection of Figs 3-4 reveals that the real house (supposed to be energy efficient) has not the lowest cooling load all the year. Indeed, from March to May the lowest cooling load corresponds to configuration #4 for the two floors. This configuration also exhibits the lowest cooling load during September-December 2009 in the 2nd floor. It is clear from these results, that walls insulation is not suitable in the context of the present study.

The above comments may be summarized as follows,

1. Roof insulation has a great beneficial effect around all the year.
2. The overhang along the South wall of the 2nd floor prevents against overheating and thus has a net beneficial effect in summer in the 1st floor, although it slightly increase heating load.
3. The beneficial effect of external walls insulation around the year is not clear. This point is under consideration.

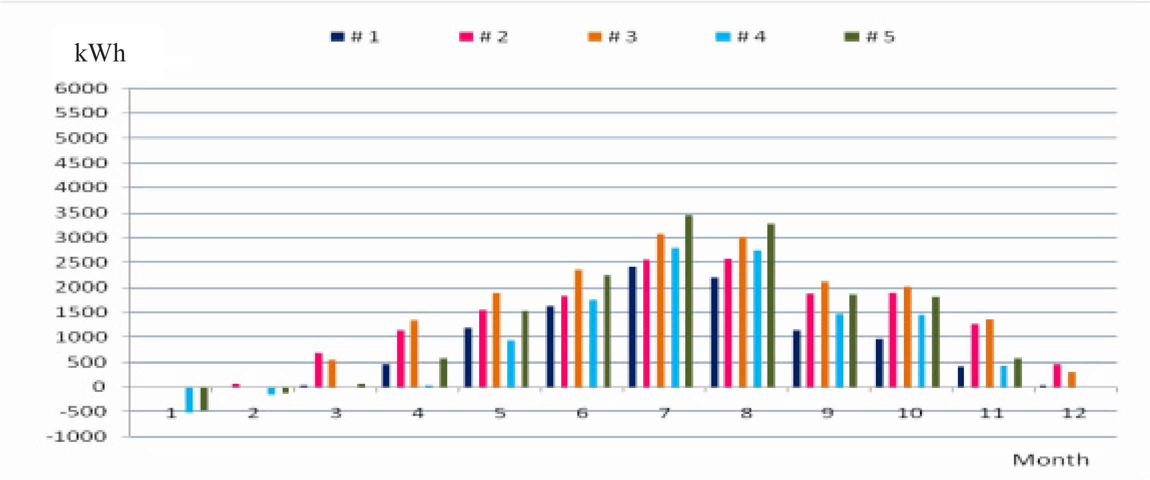

Figure 3: Cooling/heating loads of the 1st floor.

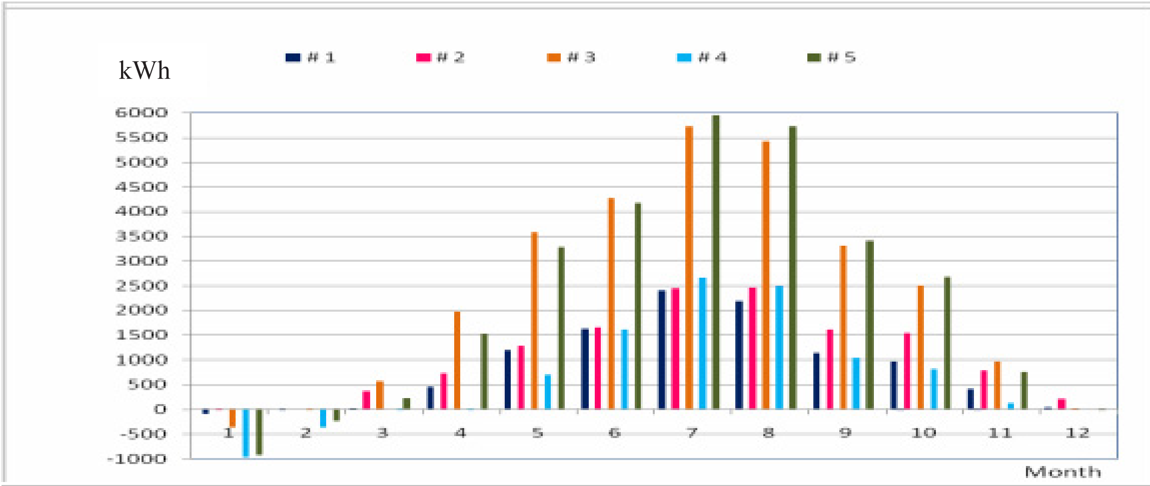

Figure 4: Cooling/Heating loads of the 2d floor

4. Conclusion

A transient multi-zone thermal modeling of a villa type house, located in the Marrakech (Morocco) suburb, was conducted. The house was designed to be energy efficient and environmentally friendly by integrating some passive techniques. In the present work, we were interested in three techniques: the overhang, thermal insulation of the roof and external walls. Most of these systems are unusual in Marrakech residential buildings. By comparing 5 configurations of the house we have been able to assess the performance of each passive technique. The effects of these passive techniques on air temperature inside the building, as well as on its cooling/heating load, were analyzed. The results show that some of these systems reduce the maximum air temperature, while some others act only on the minimum temperature by increasing it. The former systems reduce the cooling load and are very efficient in summer. This is the case, especially, of the roof thermal insulation. The other systems reduce heating load and have a small effect on cooling load. It should be mentioned that heating load of the studied house is negligible compared its cooling one. One of the interesting results is that, corresponding to the effect of external walls thermal insulation. This insulation has a small beneficial effect on the heating load and decreases the cooling one at the beginning and the end of hot season; while it increases the cooling load during some months. Therefore, the beneficial effect of this wall thermal insulation is not clear and needs further investigation. It should be mentioned that the present modeling was conducted in drastic conditions: glazed areas were not sun protected (no stores), the house was not ventilated, infiltrations are not considered and ground coupling is not considered.

The present work is the first part of a project aiming to determine what are the most efficient passive techniques for Marrakech climate. Theoretical and experimental work is in progress to improve this study and extend it to the Earth-to-Air Heat Exchanger.

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