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The Impact of Exterior Walls Materials on Energy Consumption in a Domestic House in Desert Climate

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***Abstract:** The purpose of this scientific article is the study of the impact of the exterior walls materials of a house in a desert climate on its annual energy needs in terms of heating and cooling essentially, but also on its internal and solar energy gains and its losses in relation with infiltration, transmission and ventilation. In this regard, simulations were carried out with five different locally used materials. The final purpose is to determine the suitable exterior materials for dwellings in the desert geographical area for energy saving while guaranteeing the thermal comfort. Based on our analysis, it was revealed that a good choice of exterior walls materials can save a considerable amount of energy throughout its life cycle.*

***Keywords :** Building energy consumption, Exterior Walls, Energy Efficiency, energy saving, Sustainability.*

I. INTRODUCTION

Morocco is highly dependent on imported energy, over 91% of energy supplied comes from abroad. This is a significant burden on the balance of payments, and, insofar as some energy supplies are subsidized, a drain on the budget. [1] One of the major priorities of the new energy strategy developed by Morocco is to increase the contribution of renewable energies in electricity production to 42% by 2020 and to 52% by 2030. In the world, the buildings and buildings construction sectors combined are responsible for 36% of global final energy consumption and nearly 40% of total direct and indirect CO2 emissions [2]. In Morocco, the building is the largest consumer of final energy with a share of 25% of the total energy consumption of the country, of which 18 % reserved for residential and 7% for the tertiary sector and this energy consumption is expected to increase rapidly in the coming years [3]. Types of materials of construction are one of the key factors in every energy efficiency policy that impact the building energy consumption.

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II. METHODOLOGY

To understand the impact of exterior walls materials on the annual energy needs in terms of heating and cooling, on the internal and solar energy gains and finally on the energy losses in terms of infiltration, transmission and ventilation, we studied a thermal behavior of a simulated small house, located in the city of Errachidia in the South-East of Morocco, with a specific technical and architectural characteristics that are defined and detailed below and thus we established simulations with at each time, a well-defined material.

For this purpose, we worked with "TRNSYS 16" a complete and extensible simulation environment for the transient simulation of systems. It is used by engineers and researchers around the world to validate new energy concepts, from simple domestic hot water systems to the design and simulation of buildings and their equipment, including control strategies, occupant's behavior, alternative energy systems (wind, solar, photovoltaic, hydrogen systems), etc. [4].

We used a "type 56" a multi-zone building model of TRNSYS and its visual interface "TRNBuild".

To generate meteorological data for our geographic area, we used Meteonorm, a meteorological database containing comprehensive climatological data for solar engineering applications at every location on the globe. It's a standardization tool permitting developers and users of engineering design programs access to a comprehensive, uniform meteorological data basis. [5].

III. METEOROLOGICAL CHARACTERISTICS

The city of Errachidia is located 1045m above the sea, it's characterized by its desert climate whose main characteristics are detailed below (the historical data generated from Meteonorm is 1991–2010 for irradiation and 2000–2009 for the other parameters):

A. Temperature:

A significant temperature difference, seasonal as well as daily, between very high temperatures on the summer (39°C as average at the month of July) and very low temperatures of the winter (3°C as average in January) (Fig1).
The temperature reaches 42°C in July and falls below 0°C in the month of January (Fig 2);

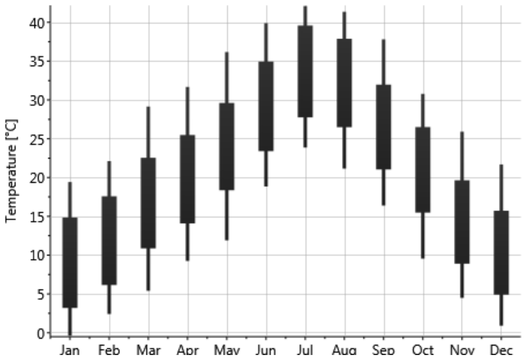


Fig. 1.Average minimum and maximum temperature per month

B. Sunshine Duration:

An important astronomical sunshine duration throughout the year, which varies between an average of 14 hours/ day in May, June and July and 10 hours/day in the months of November, December and January. In terms of effective sunshine duration, it varies between 10,2 hour/day in June and 6,7 hour/day in January and December (Fig 2);

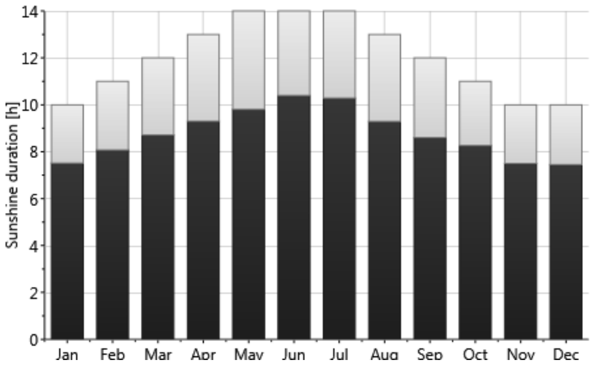


Fig. 2.Sunshine duration(in black) and astronomical sunshine duration (in grey)

C. Global Radiation

Global radiation varies between 110 kwh/m^2 in December, and exceeds 240 Kwh/m2 in May, June and July.

The diffuse radiation varies between 20 kwh/m2 in January and 58kwh/m2 in July (Fig 3).

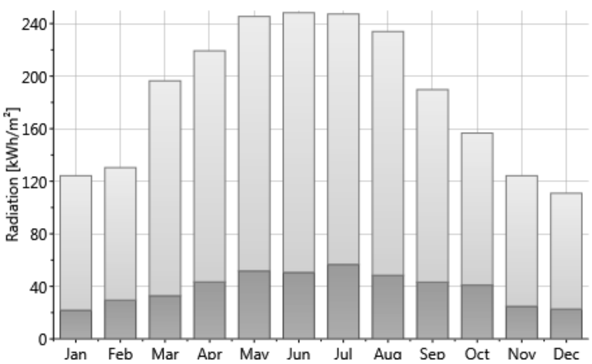


Fig. 3.Diffuse radiation and global Radiation (in light grey)

These entire data illustrate the energy potential of this geographical area, but also the possible overheating that can face all the dwellings in this area especially in summer.

D. Precipitation:

recipitation are mainly rainy and rarely snowy, they are very rare and unequally distributed over time and space (between an average of 3mm in July and 29mm in October). The average number of rainy days per year is around 29 days (Fig 4);

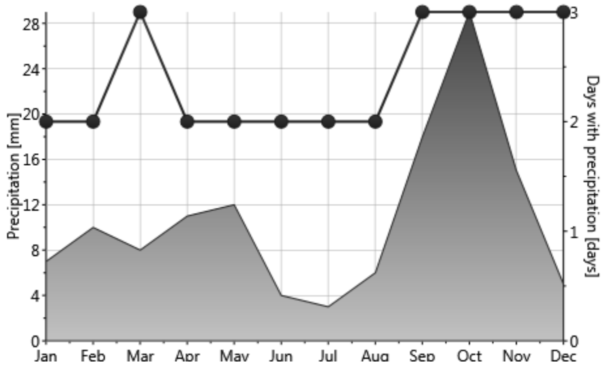


Fig. 4.Precipitation and days with precipitation

E. Areas and volumes

The house object of our thermal simulations has 69m^2 as gross floor area, 57m2 as a net floor area and 171 m^3 as a net volume. The length of the house is 10,60m and the width is 6,60m. It's composed of a living room, a bedroom, a dressing, a kitchen and a bathroom (Fig 5 and Tab I);

Table- I: Areas and Volume of the Dwelling Reference

Rooms	Height (m)	Surface (m^2)	Volume (m^3)
Room	3,00	9,79	29,37
Living room	3,00	22,95	68,85
Bathroom	3,00	4,69	14,07
Kitchen	3,00	7,25	21,75
Dressing	3,00	6,19	18,57
Hall	3,00	6,15	18,45
Net floor area	-	57,02	171,06
Gross floor area	-	69,96	209,88

F. Technical Details

The type of glazing used in this dwelling reference is a simple glazing with a thermal transmission of 5.74 W/m^{2}k

The technical details of construction, used for simulations such us thickness, conductivity, capacity and density of materials, are explained below (Tab II).

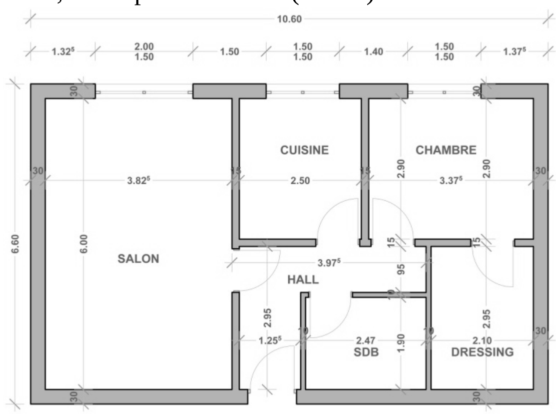


Fig. 5.Plan of the house simulated

Table- II: Technical Details of the Dwelling Reference

Constitution (From The Inside To Out)		Thickness (m)	Conductivity (Kj/Hmk)	Capacity (Kj/Kg K)	Density (Kg/m³)	Thermal Transmission (W/m².K)
Floor	Floor Tiling	0,01	1,3	0.801	790	1.623
	Cement Screed	0,05	2,52	1	1300	
	Concret Slab	0,15	4.068	1	1400	
	Hardcore	0,15	2,52	1	1800	
		Tot : 0,36				
Exter walls Case 1 : Hollow Brick	Plaster Mortar	0,02	1,26	1	1200	0.370
	Hollow Brick	0,10	1,69	0.794	720	
	Air Gape	0.11	0,216	1.227	1	
	Hollow Brick	0,10	1,227	0.794	720	
	Cement Mortar	0,03	4,5	0.84	2000	
		Tot : 0,36				
Exter walls Case 2 : Concrete block	Plaster Mortar	0,02	1,26	1	1200	0,438
	Concrete block	0,10	3.46	0,65	1300	
	Air Gape	0.11	0,216	1.227	1	
	Concrete block	0,10	3,466	0,65	1300	
	Cement Mortar	0,03	4,5	0.84	2000	
		Tot : 0,36				
Exter walls Case 3 : Limestone block	Plaster Mortar	0,02	1,26	1	1200	2.606
	Limestone block	0,31	7.92	0,8	2400	
	Cement Mortar	0,03	4,5	0.84	2000	
		Tot : 0,36				
Exter walls Case 4 : Rammed earth	Plaster Mortar	0,02	1,26	1	1200	1.523
	Rammed earth	0, 31	2.7	1.3	1700	
	Cement Mortar	0,03	4,5	0.84	2000	
		Tot : 0,36				
Exter walls Case 5 : Rammed earth with straw	Plaster Mortar	0,02	1,26	1	1200	0.299
	Rammed earth with straw	0, 31	0.7	1.3	1300	
	Plaster Mortar	0,03	1,26	1	1200	
		Tot : 0,36				
Roof	Plaster Mortar	0,02	1,26	1	1200	1.702
	Concret Slab	0.25	4.068	1	1400	
	Bitumen Roofing	0.02	1.805	1	1700	
	Cement Screed	0,05	2,52	1	1300	
	Roof Tiling	0,01	1,3	0.801	790	
		Tot : 0,35				

G. Internal scenarios

- For heating, the set indoor temperature is 22 °C;
- For cooling, the set indoor temperature is 26 °C;
- Both heating and cooling are scheduled to maintain the relative humidity between levels of 30% and 60%;
- The infiltration is fixed at 0.6 volume per hour;
- Ventilation rate is set at 0.6 volume per hour; the house is ventilated every day in the early morning between 06 and 07 AM and in the evening between 20 and 21 PM.
- The sensible energy gain due to convection of people inside the area is set for 02 people in mode (Seated light, work, typing), both their sensible and latent heat are 75 W/Person, and their adjusted total heat is 150 W/Person.
- We used incandescent lamps with a total heat gain of 10 W/m²; the convective part is 10%.

IV. Results and Discussion

Based on the results (Fig 10), we can bring out the following general results :

- The hollow brick is the less energy consumption material in terms of energy needs for heating and cooling.
- The limestone block is the material that marks the most gains and losses in term of energy.

The data and graphs that follow explain in detail the results obtained for each material in terms of energy needs, gains and losses.

A. In Terms of Energy Needs:

Based on the results (Fig 6 and Fig 7), we can affirm that:

- The hollow brick (5611 Kwh/Year) is the best choice for less energy consumption in terms of energy needs for heating and cooling.

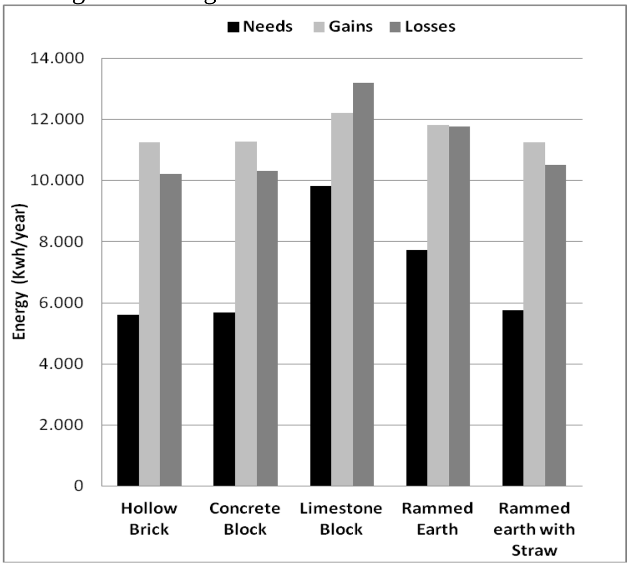


Fig. 6. Annual energy needs, gains and losses

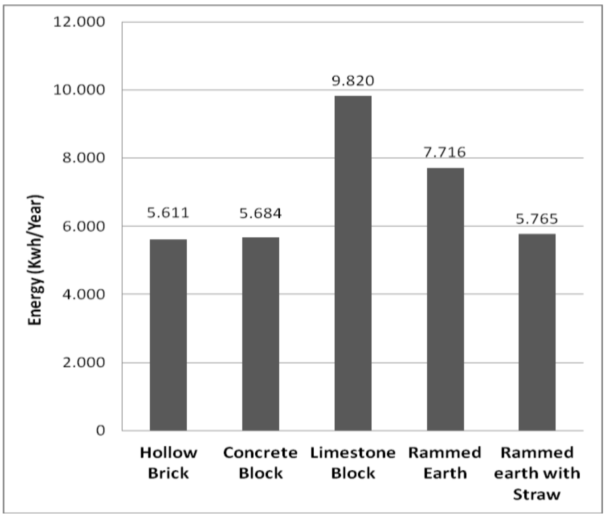


Fig. 7. Annual energy needs (heating and cooling)

- The concrete block (5684 Kwh/year) and the rammed earth with straw (5765Kwh/Year) marks similar results in terms of cooling energy saving as hollow brick.
- The rammed earth (7716 Kwh/Year) consumes more energy comparing to the materials mentioned before.
- The limestone block (9820 Kwh/year) is the most energy needs consuming material.

B. In Terms of Energy Needs for Cooling:

For energy cooling we obtained the following results:

- The rammed earth with straw (3220 Kwh/Year) is the least consuming energy for cooling (Fig 8), it's the best material among the five others for hot seasons.
- The hollow brick (3287 Kwh/Year) and the concrete block (3290 Kwh/Year) score too, less consuming energy for cooling.
- The rammed earth (3810 Kwh/Year) and the limestone block (4383 Kwh/year) consume more energy for cooling.

The cooling is active in a total of 7 months (from April to October) materials (Fig 10, Fig 11, Fig 12, Fig 13 and Fig 14). As the outside temperature rises, cooling becomes significant especially in May, June, July, August and September.

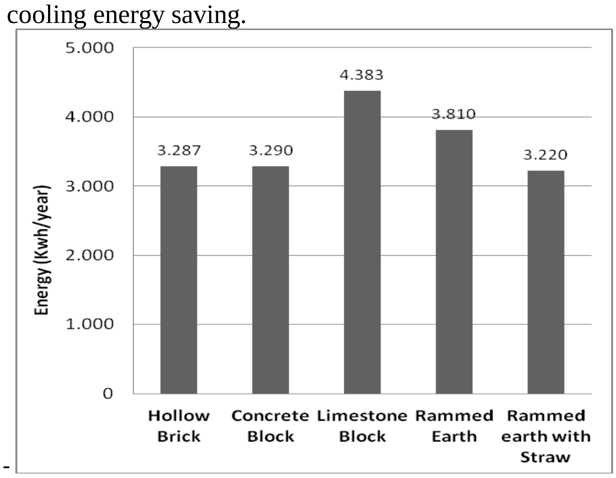
The temperature in the before mentioned month vary between 25°C and 42°C (we insert here as an example, the results of hollow brick during the whole year (Fig 9) in which we can see the equivalence of the before mentioned months in hours (from 2880 hr (early May) to 6552 hr (end of September) in relation with ambient temperature).

The month that shows more energy consumption in terms of cooling is July, during which the outside temperature exceeds the 40 °C, followed by the month of August (Fig 10, Fig 11, Fig 12, Fig 13 and Fig 14).

The total energy consumption at the level of April and October remains less important due to the fact that the ambient temperature is not yet so hot.

Finally, from the results we (deduct that:

- The limestone block is not a good choice for hot seasons or hot arias.
- The rammed earth with straw is a good decision in terms of cooling energy saving.



- **Fig. 8. Annual cooling energy needs**

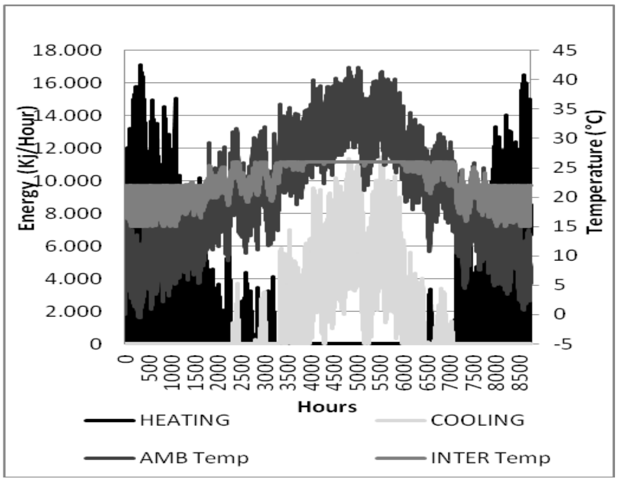


Fig. 9. Hourly heating and cooling energy needs in relation with ambient and interior temperature (case of hollow brick)

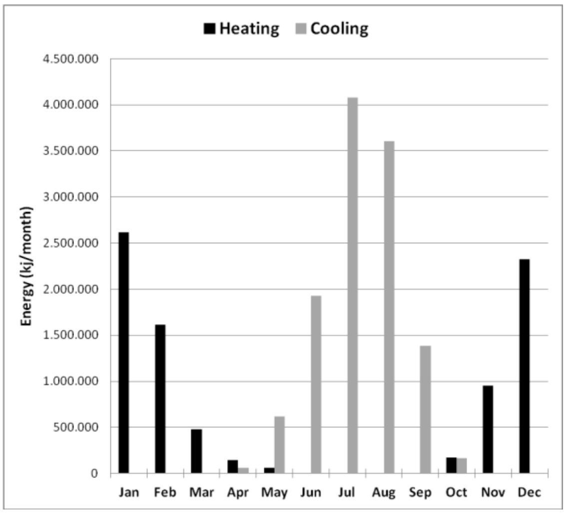


Fig. 10. Monthly cooling and heating energy needs (case of hollow brick)

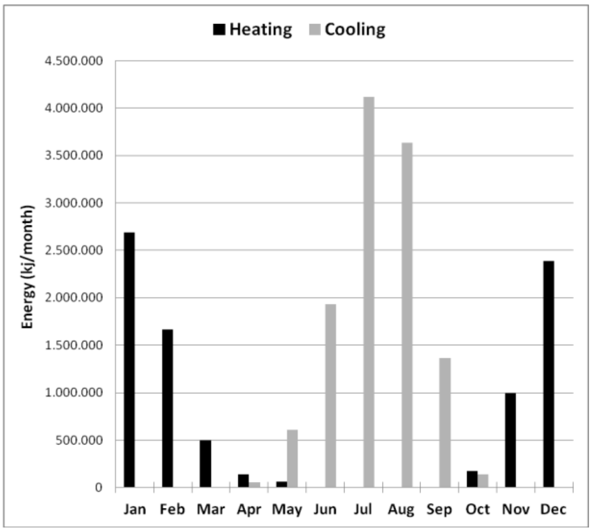


Fig. 11. Monthly cooling and heating energy needs (case of concrete block)

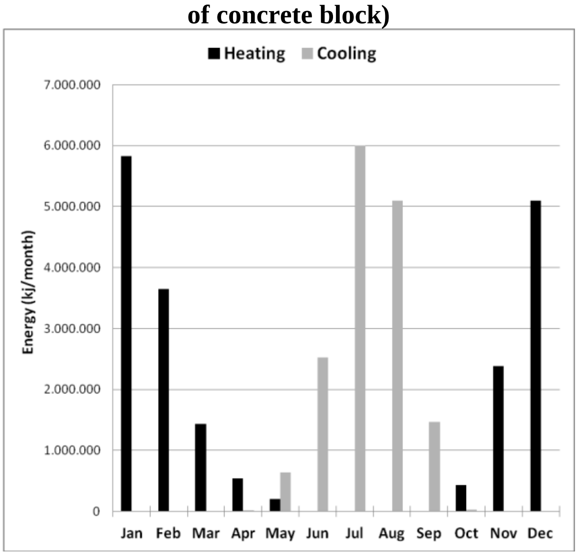


Fig. 12. Monthly cooling and heating energy needs (case of limestone block)

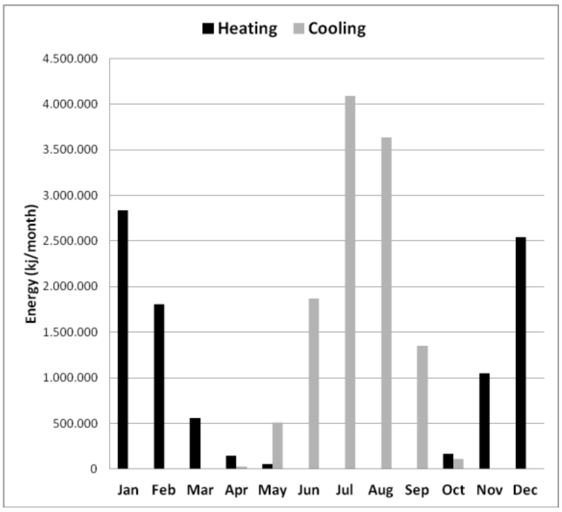


Fig. 14. Monthly cooling and heating energy needs (case of rammed earth with straw)

C. In Terms Of Energy Needs For Heating:

For energy heating we obtained the following results (Fig 15):

- The hollow Brick (2324 Kwh/Year) is the least energy-consuming orientation.
- The concrete block (2393 Kwh/Year) and the rammed earth with straw (2545 Kwh/Year) marks similar results in terms of heating energy saving as hollow brick.
- Rammed earth (3907 Kwh/Year) consumes more heating energy.
- In the last position the limestone block consume 5436 Kwh/Year for the heating which is too high comparing to the other materials. It’s the most heating energy consuming material.§

Heating is active in 8 months (Fig 10, Fig 11, Fig 12, Fig 13 and Fig 14) from October to May and it achieves significant energy consumption in November, December, January and February, since the outside temperatures realize significant drops (see the example of results of hollow brick during the whole year (Fig 9) in which we can see the equivalence of the before mentioned months in hours (from 7296 hr to 8760 hr and from 0hr to 1416 HR) in relation with ambient temperature).

The month that shows more energy consumption in terms of heating, is January, as the outside temperature goes down by 0° , followed by December, February and Mars.

Consumption in the months of April, May and October are not significant, as the outside temperature is not yet gone down.

Finally, from the results we can affirm that:

- The hollow brick is a good choice in terms of heating energy saving.
- The limestone block is not a good choice for heating energy saving.

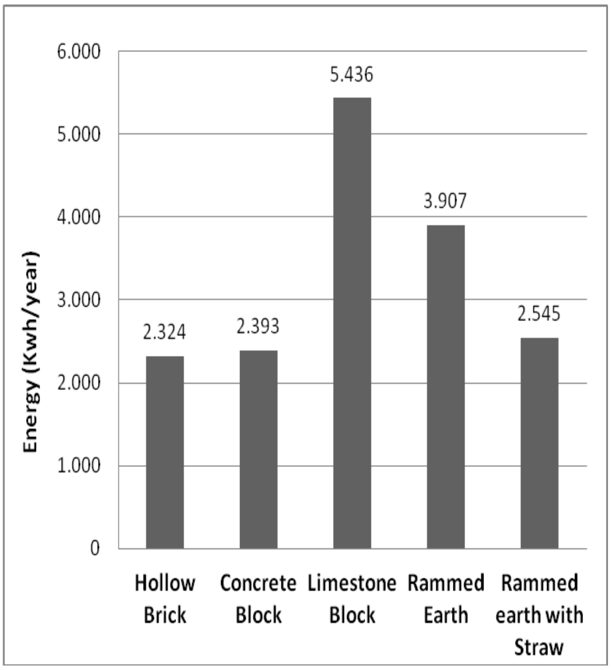


Fig. 15. Annual heating energy needs

D. In Terms of Energy Gains

For energy gains we obtained the following results (Fig 16):

- The limestone block (12200 Kwh/Year) and the rammed earth (11811 Kwh/Year), are the most gaining energy material.
- The Hollow brick (11248 Kwh/Year), The concrete block (11265 Kwh/Year) and the rammed earth with straw(11258 Kwh/Year) have approximate energy gaining values and represent each one of them, approximately the half, of limestone block energy gaining.

The repartition of gains due to infiltration, transmission and ventilation in addition to internal and solar gains are almost identical on all materials (Fig 17). Indeed, solar gains represent the most part of gains followed by internal gains.

We can figure out from these results that the limestone block is the most gaining energy material.

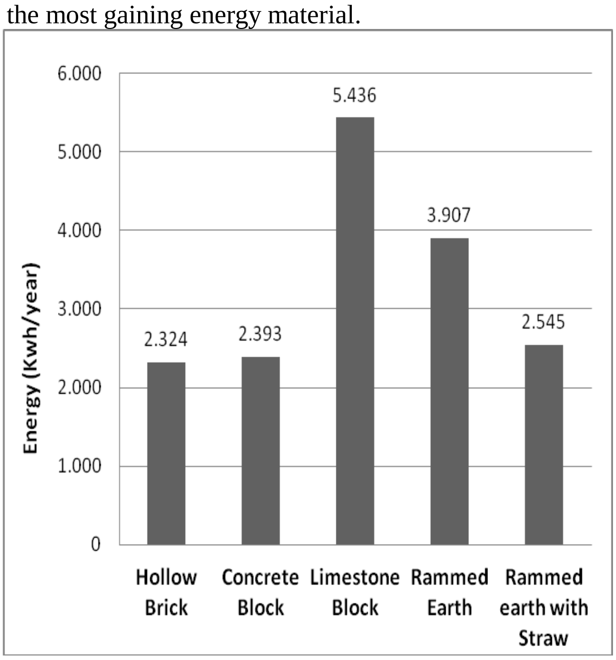


Fig. 15. Annual heating energy needs

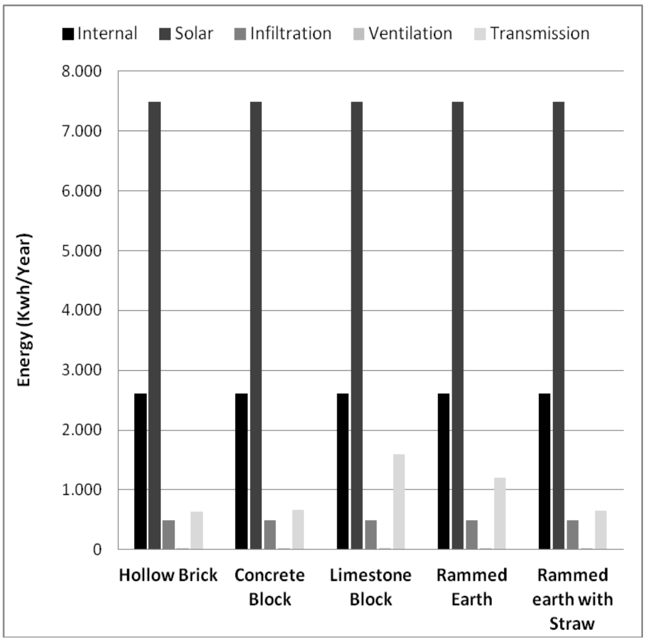


Fig. 17. Partition of annual energy gains

E. In Terms of Energy Losses

For energy losses we obtained the following results:

- The energy losses don't differ radically from a material to another one, Although, the limestone block (13185 Kwh/Year) is the most losing energy material, as it is the most energy gaining material (Fig 16), the same conclusion can observed for rammed earth which scores 11774 (Kwh/Year) of losses. (Fig 18)
- The rammed earth with straw (10515 Kwh/Year), the concret block (10300 Kwh/Year) and the hollow brick (10216 Kwh/Year) have approximate energy losses values and marks least energy losses. (Fig 18)

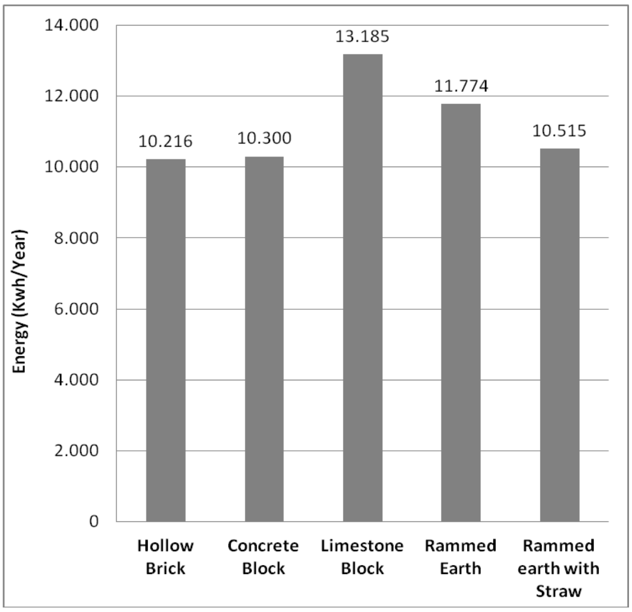


Fig. 18. Annual energy losses

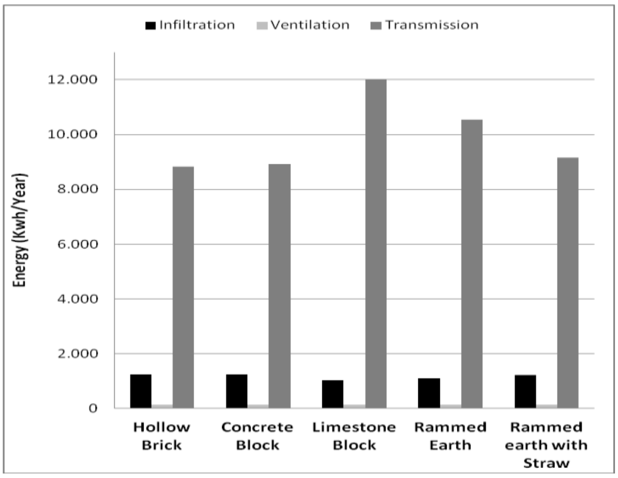


Fig. 19. Distribution of Annual energy losses

The common part of the energy losses are realized by transmission effect (more than 86%), followed by infiltration (less than 12%), and finally by ventilation which remain insignificant (1%).

The energy losses are realized from January to May and from September to December (Fig 20, Fig 21, Fig 22, Fig 23 and Fig 24).

The most important energy losses are realized in autumn, and winter exactly on the months of November, December, January and February. Although, January, remains the most energy losing month.

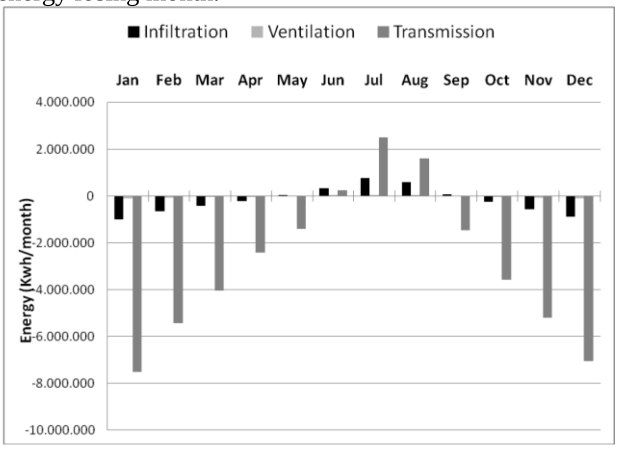


Fig. 20. Monthly energy looses and gains due to infiltration, ventilation and transmission. (Case of rammed earth)

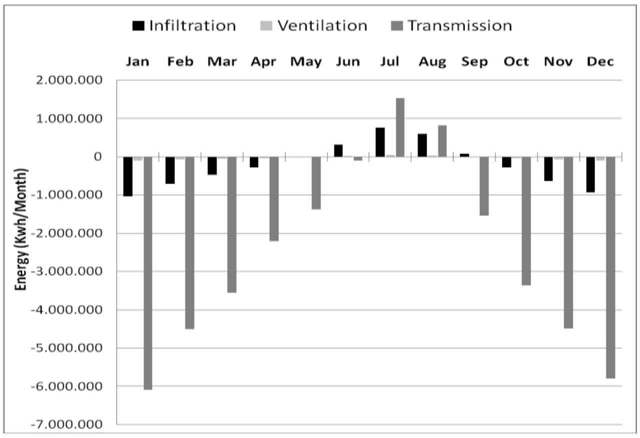


Fig. 21. Monthly energy looses and gains due to infiltration, ventilation and transmission. (Case of rammed earth with straw)

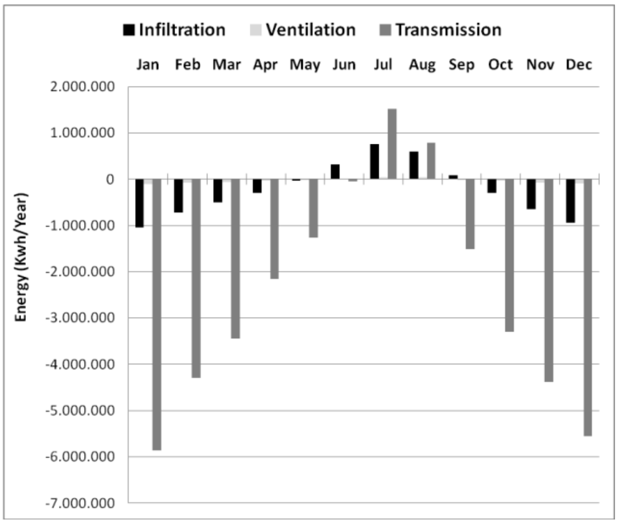


Fig. 22. Monthly energy looses and gains due to infiltration, ventilation and transmission (Case of hollow brick)

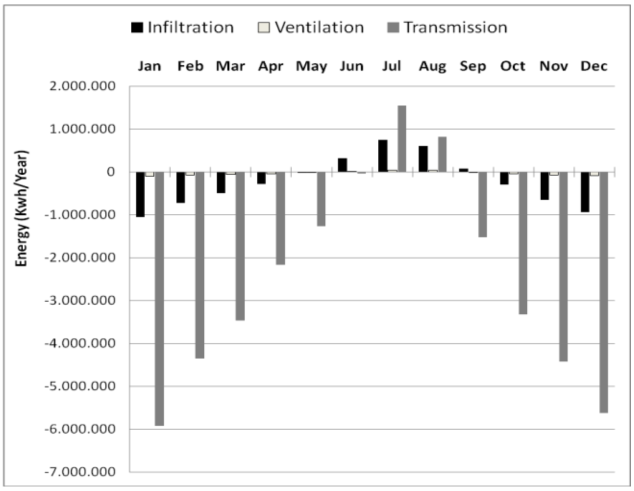


Fig. 23. Monthly energy looses and gains due to infiltration, ventilation and transmission. (Case of concrete block)

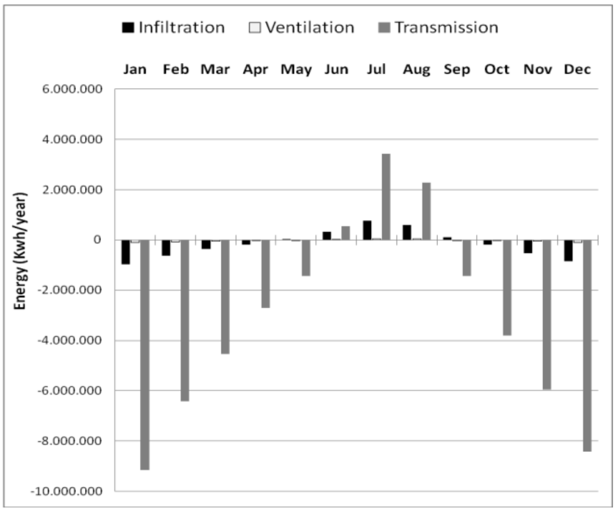


Fig. 24. Monthly energy looses and gains due to infiltration, ventilation and transmission. (Case of limestone bloc)

It is so important to indicate that the effects of transmission, infiltration and ventilation, contribute furthermore to energy gains that occur in the summer period (between June and September). Although these amount of energy gains remain negligible in comparison with the losses that it generates.

F. Explication

These results can be explained by the thermal characteristics of these different materials:

For the hollow brick, the concrete block and the rammed earth with straw: their thermal conductivity coefficients as well as those of thermal transmission of their external walls allow them to stop the heat they receive, and thus to play a role of insulation of the house in relation kto the outside temperatures.

On the other hand, these three materials have good thermal inertia efficiency, providing them with a large capacity for storing and returning heat.

The hollow brick, due to its thermal characteristics in particular its thermal conductivity (1.69 W / mk), it marks the least energy needs but also the least energy gains and losses.

It should be noted that the rammed earth with straw, although its walls have the lowest thermal transmittance (the most insulating) and the best thermal inertia capacity, it is not the best material in terms of economy of energy needs (heating + cooling), since it marks higher energy losses than the hollow brick and the concrete block.

For rammed earth and limestone block, because of their thermal characteristics, they mark more consumption in terms of energy needs. Limestone block has the highest coefficient of thermal conductivity (7.92 W / m.k), which makes it more conductive than other materials, thus allowing a good amount of energy to pass through these walls. Limestone block also has a high thermal inertia capacity (0.8 KJ/kg.k), which gives it a high storage capacity and heat recovery. All these characteristics explain to us why it marks the most energy gains but also the most energy losses.

In the same way, the concrete block and the rammed earth with straw, mark approximate results as the hollow brick in terms of energy needs, gains and losses.

For rammed earth, it is approximate to limestone block results, in fact, it has a high thermal inertia capacity (1.3 Kj/Kg.k), hence its better results in terms of energy gains; however, its characteristics in terms of thermal conductivity (7.92 W/m.k) and thermal transmission of its walls (2.60 W/m2.k) explain its significant energy losses by transmission.

Rammed earth with straw has a better thermal capacity (1.3 Kj/Kg.k), and thermal transmission of its walls (0.29 W/m2k), it marks the best result in terms of saving of energy needs for air conditioning , in summer globally. Indeed, these features allow reducing summer indoor temperatures, during the day, by absorbing unwanted heat influx and, conversely, it can reduce nighttime temperature drops, by releasing the heat stored in the day. The ventilation during this period, manages to ensure the best results in terms of summer comfort.

V. CONCLUSION

In this study, we carried out simulations to study and analyze the exterior walls materials in terms of their impact on energy needs, gains and losses of a house in order to determine the adequate exterior walls material for energy saving in a desert climate of the city of Errachidia in Morocco.

For this purpose, we worked with both “TRNSYS 16” a complete and extensible simulation environment and “Meteonorm”, a meteorological database.

At the end of the analysis, the results show us that the exterior walls materials have a significant impact on the energy consumption of heating and cooling and thus the annual energy bill. We show also the following results:

- Hollow brick, concrete block and rammed earth with straw are the least energy-consuming, they are the best choices in terms of energy saving, since they make a balance between energy gains and losses;
- Limestone block is the most energy needs consuming as it marks the most energy losses between all other materials;

Finally, we expect that these results will participate to reach objectives of the new energy strategy - 2030 drawn up by Morocco. We hope too that these results will push architects, building owners and governments to take seriously into consideration the type and the thermal characteristics of materials of construction especially those of exterior walls, as they constitute an important part of the buildings envelope.

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AUTHORS PROFILE

Omar Bourass, Morocco, 1986, Architect and Urbanist, he is a principal Architect and a Head of Service of Urban Observation Phenomena in the Direction of Urban planning in the Department of Land, Urban Planning and Housing in Morocco. He is an expert in the urban planning field. He got an Architecture degree, a Master degree in sustainable transport and urban mobility, and he would defend soon his Doctorate thesis about the energy efficiency in the building.

He was in charge, in the Urban Planning Agency, of the study of the Master Plans of Urban Planning and Plans of Development of cities in Morocco as well as various specific studies such as architectural charters and urban projects

He worked in architectural firms on many architectural competitions and planning projects. He was, for years, responsible for strategic studies related to the urban and socio-economic development of big Cities in Morocco (Rabat, Tangier, Marrakech…). Currently, he is Head of Service in charge of studies related to digital transformations of lands and smart cities.

Mr. Bourass is author of scientific publications in international journals and participated in communications in International Conferences.

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From 2000 to 2019 he has many responsibilities, he was director in charge of Scientific Research and Cooperation at EST-Salé, University Mohammed V (2014-16), he is an expert member of the National Agency for the Quality Assessment of Higher Education and Scientific Research (since 2015), he was manager of the Continuing Education Service (2008-2014), he was Chief of Industrial Maintenance Department (2000 to 2008), he was Coordinator of the "Industrial Maintenance" DUT program (2006-2010), he was Coordinator of the Master's degree program "Management and Consulting in Information Systems" (2007-2014)….

He is author of about 25 scientific publications in international journals and 50 communications in the International Conferences and two Didactic books for the World Health Organization (2000). He was a coordinator of many research and development projects. He was a members' jury of prize and doctoral thesis and member of the Scientific Committee of more 20 International Scientific and pedagogic Conferences (Canada, Japan, Swiss, Maghreb, Benin, Belgium…). He supervises now 10 PhD students and he supervised 30 MSc theses.

Pr. Aziz Et-tahir was awarded by the International Association of University Pedagogy (AIPU International) at the 25th International Congress of the AIPU, Montpellier-France, 19-22 May 2008 and at the 28th International Congress of the AIPU, Mons-Belgium, 17-23 May 2014. About professional associations, he was Vice-President (2012-18 appointed in Canada) and member of the International Board of Directors (2009-2018) of the International Association of University Pedagogy (AIPU International), he was a founding member of the Moroccan Society of Acoustics (SCA) (2010), he was (since 2000) founding member and member of the Board of Directors of the Moroccan-French Association of Energy and the Environment (AMFREE), (since 2006).

He is accredited with the mastership of controlling gas and steam pressure equipment by the Ministry of Energy and Mines (since 1997).

Pr. Kamal Kettani, Professor at University Mohammed V in Rabat since 2000, Ph.D. in pharmaceutical and biological sciences at University of Lille2, France, 1994 and Empowerment to Lead Research in environment and health at University Mohammed V in Rabat. He is Member of Materials, Energetics and Acoustics Team (MEAT) in the Superior School of Technology.

From 2000 to 2019 he had several responsibilities, among others:

- Expert Member of the National Agency for Evaluation and Quality Assurance of Higher Education and Scientific Research ANEAQ (2015)
- member of the examination commission of recruitment of assistant professor of higher education; EST-Salé (2016)
- Expert member of the Evaluation and Accreditation Committee of the Ministry of National Education, Higher Education, Management Training and Scientific Research (2016)
- Coordinator of the Professional Licensing Program "Instrumentation and Biomedical Maintenance" (since 2014) "Maintenance of Scientific Equipment" (since2015)
- Elected Board Member of Mohammed V University - Agdal (2005)
- Participation in the coordination of the structuring of research at EST-Salé (2005)
- Member of many research and development projects.

He is an author of many scientific publications in international journals and pedagogic and scientific communications in the International Conferences.