The Effects of Envelope Building Materials on Thermal Comfort and Energy Consumption. Case of Hot and Dry Climate

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Abstract

Envelope Building materials play an important role in architecture by providing protection necessities, comfort, and technical performance while promoting an architectural language and an image. The building envelope represents all the surfaces of a space, which consist of opaque parts such as walls, floors and roofs and transparent parts such as windows and openings. The building envelope is the partition between the external and internal environment of the building which influences the heat transfer between the two environments so it has a direct impact on the thermal comfort sensation which also influences the energy consumptions. In this research we focus on the opaque building materials of the envelope and their contribution in the thermal comfort and the energy consumption, we investigate the impact and the thermal behavior of different envelope configuration materials under the climatic conditions of Biskra, Algeria a hot and arid climate. We compare the thermal performance of different materials using in situ measurement using "Testo 480" a hygrothermal scale and by analyzing the results of a different simulation using
"DesignBuilder v5.5" to perform a thermal and energy analysis. The results show that choosing a multilayered isolated envelope such as double red brick isolated wall will likely affect positively the level of the indoor thermal comfort.

Keyword: Envelope; Building Materials; Thermal Comfort; Energy Consumption; Hot and Dry Climate.

1. Introduction

In the last centuries, the world confronted a substantial development movement that touched all aspects of life, a great part of concepts has changed, hence the concept of architecture has changed from the art of building to a plastic practice in another word the focus has shifted to the image and the aesthetic of the building rather than the environmental aspect which has disregarded, Therefore the world now is facing a double challenge: first, the problem of security of energy supply and, the fight against climate change. (Thiers S., 2008).

Energy consumption is one of the world's problems, which is the result of the environmental damages caused by the irrational consumption of energy. In addition, the global energy crisis has made the world less inclined to seek alternative sources. The energy consumption of the building falls under the many adaptation needs of users from the air conditioning, heating ventilation and lighting using HVAC systems in order to reach the comfort of the user, as a result buildings are accounted for about 40 % of the global energy use (Kolokotsa, D et al, 2009).

As stated by Ould-Henia (2003), the new architectural models produced in Algeria during the last decades which they called modern constructions are more energy consumers, less adaptable to their environment and regarding the climatic aspect.

Thermal comfort is a requirement for the user within the space, hence resorting to the use of HVAC systems become a necessity for the user in order to reach and ensure his comfort which leads to an increase in the energy consumption, it’s up to the architect during the design phase to reach the limits of thermal comfort in a passive ways which can only be achieved through a good understanding of the climatic conditions and the environmental context for a good integration of the building in its location , thus contribute to reducing the energy consumption of the building.

In hot and dry climates *context* energy required in the building goes towards providing thermal comfort, especially in summer’s sessions thus it’s possible by a passive architectural disposition, techniques and a good choice of building materials. (Ould-Henia, 2003).

According to Gezer, (2003) Achieving thermal comfort in a building starts with the knowledge of the climate in question and passive strategies to control this climate in order to provide the right design approaches for maintaining comfort. The selection of envelope building materials is the major and prime control in maintaining the thermal comfort of occupants.

The building envelope is the barrier between the interior and exterior of the building; therefore it plays an important role in controlling the climatic factors, either by benefiting or protecting from them in order to reach thermal comfort.

The Studies have shown that the effect of the envelope material it is due to their thermal and physical properties which determine the thermal efficiency of the materials.

Building envelope materials are one of the elements of the building that influences directly indoor thermal comfort because it is a barrier between two environments; the inside and the outside thus it plays an important role in controlling climatic factors (Gezer, 2003). Many researches has found that the impact of building envelope materials on thermal comfort and heat transfer is due to its thermal-physical characteristics, according to Givoni (1978) thermo-physical properties have to be considered while choosing a building material and decrement factor should be taken into account. He emphasizes the combined effect of material properties and color. The thermal resistance of the materials plays an important role in heat flow and increasing the total thermal resistance the envelope; a wall or a roof by reducing the heat flow through the building. Therefore in this research, we investigate how to achieve thermal comfort in a hot climate by making the Wright choose of envelope materials that resist and work well with this type of climate conditions.

2. The Literature Review

2.1. Indoor Thermal Comfort

Thermal comfort is a necessity in the indoor space since users are spending the majority of their time indoors, it become an obligation for architects and technicians to achieve it with their design, which has spawned large studies in the scientific literature to define thermal comfort. According to Givoni (1978), thermal comfort is a state of thermal balance between the human body and his environment also is the Conditions for which the body's self-regulation mechanisms are at a minimum level of activity. In the Norm “EN ISO, 7730” Thermal comfort is often defined by the satisfaction expressed with the thermal environment.

In the ASHRAE Handbook (2011) it is defined as "*the condition of mind which expresses the satisfaction with the thermal environment* ".

According to Moudjalled (2007) the difference between these definitions is according to the aspect taken into consideration; the physiological, sensory and psychological aspect, he mentioned that the concept of thermal comfort depends on the physical context and the individual characteristics,*” It is a dynamic adaptive process that integrates the different physical, physiological and psychological mechanisms”*.

2.2. Comfort and Energy Consumption

Buildings account for about 40% of the global energy consumption that is used to ensure users comfort (Yang et al, 2014). The building energy requirement generally is the amount of energy needed to maintain a suitable indoor climate for a given period of time.

This concern has led to a number of studies conducted worldwide to improve building energy efficiency. Frontczak (2011) has found in a survey of indoor environmental conditions that thermal comfort is ranked by building occupants to be the most important compared with visual and acoustic comfort and indoor air quality, it’s the most influencing factor in building energy consumptions.

According to Yang (2013), a significant proportion of the increase in energy use was due to the spread of the HVAC installations in response to the growing demand for better thermal comfort within the built environment. In general, in developed countries HVAC is the largest energy consumers, accounting for about half of the total energy consumption. In Algeria, the building sector residential and tertiary account for about 41 % of the final energy consumption According to the National Agency for the Promotion and Rational Use of Energy APARUE. Figure 1 shows Algeria's final energy consumption by sector, the building sector is the most energy consuming sector in Algeria, as a consequence of the absence of comfort and the inadaptability of buildings.

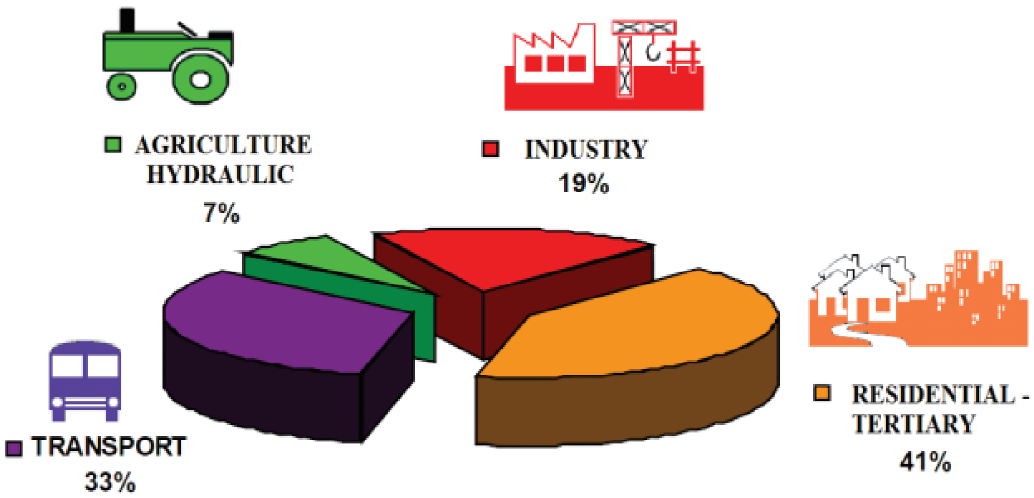


Figure 1. The Final energy consumption by sector in Algeria, APARUE 2009

2.3 Building Envelope

The building envelope is the physical barrier between the exterior and interior environments. Building envelope represents all the surfaces of a space, which consist of opaque parts: walls, floors and roofs and transparent parts: windows and openings, it is the partition between the external and internal environment of a building which influences the heat transfer between the two environments. Generally, the building envelope is comprised of a series of components and systems that protect the interior space from the environmental effects as shown in figure 2.

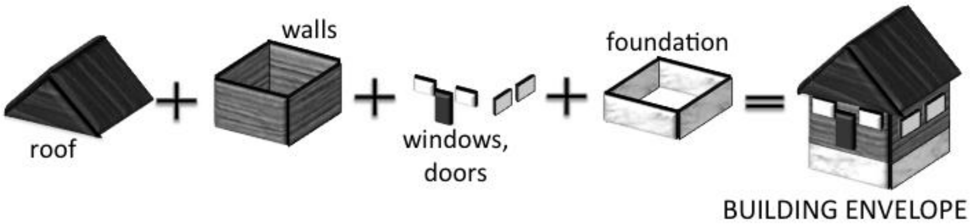


Figure 2. The component of the building envelope (URL 1, consulted March 2019)

The building envelope includes the materials that comprise the foundation, wall assembly, roofing systems, glazing, door, and all other penetration areas.

2.4. Building envelope and thermal comfort

In buildings, indoor thermal comfort depends on its envelope materials components and their physical properties and thermal such as resistance, conductivity, these thermo-physical properties determine the climatic response of the envelope. (Latreche et al, 2017)

in Balaji's (2013) study found that, in order to reduce the energy consumption in the building, it is necessary to understand the thermal performance of the building envelope on the indoor environment, he points out that most studies have found that time lag and decrement factor are the most critical performance measures of a building envelope that influence heat transfer and the indoor temperature. Envelope design characteristics affect the thermal comfort of the occupants, as well as energy consumption in the building. As such, according to Bakhlah (2015), in a hot and dry climate context, a proper passive design of building envelope can influence directly the outdoor condition, by reducing the heat gain transfer, indoor air temperature, and improving the indoor thermal condition and reducing the need for HVAC systems, which will reduce energy consumption.

Choosing building materials is essential solutions that can guarantee to maintain the comfortable conditions inside the building in all seasons, In other word choosing building envelope materials is a passive strategy that may help to ensure indoor thermal comfort.

According to Akeel (2015), Indoor thermal comfort can be achieved through the understanding of the thermal performance of the building envelope in relation to its environment.

The indoor ambiance temperature depends directly on the materials that compose the envelope (Walls, Roofs, and Widows) and their properties and how they affect heat transfer through the materials, Primary heat transport modes are: conduction, convection, and radiation as shown in figure 3.

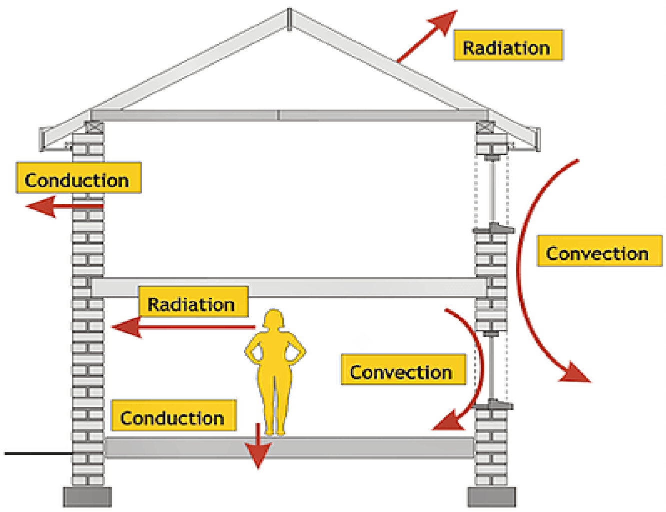


Figure 3. Heat transfer modes through the building envelope

The roof is responsible for 70.62% of the gains received while 27.11% of the thermal gains are transmitted by the four facades and 2.27% by the windows. (Necib, 2016, as cited in Latreche, 2018). A judicious treatment of the walls of the envelope according to the warm and arid climatic conditions (choice of construction materials with high thermal inertia for walls and roofing, reduction of the dimensions of windows, solar protections ... etc.) allows to guarantee an optimal comfort inside the building, even if the outside conditions are unfavorable (Izard, 1979).

3. The Study Case

In this study, an investigation of the effect of envelope building materials on thermal comfort took place to investigate the impact of different components of opaque part of the building envelope (wall, roofs, and insulations) of apartment buildings in the hot and dry climatic context of the city of Biskra.

3.1. Case of the City of Biskra: the Climatic Characteristics

The city of Biskra is a Saharan city, it has a high rate of solar radiation, it is located in the south-east of Algeria; it is characterized by a cold winter and a hot dry summer. Figure 4

The geographical features of the city: The latitude = 34.48 North, the longitude = 5.44 North, the altitude which is equal to 83 meters above sea level. Characterized by a maximum temperature in summers which reaches in the month of July 45 (C°), and a minimum temperature in winter that reaches 5 ° C during the month of January, with a rare level of precipitation(less than 30 days per year), The average relative humidity is low around 47%, with a maximum value of 65% in the month of December, and a minimum of 28.29% in July and August.

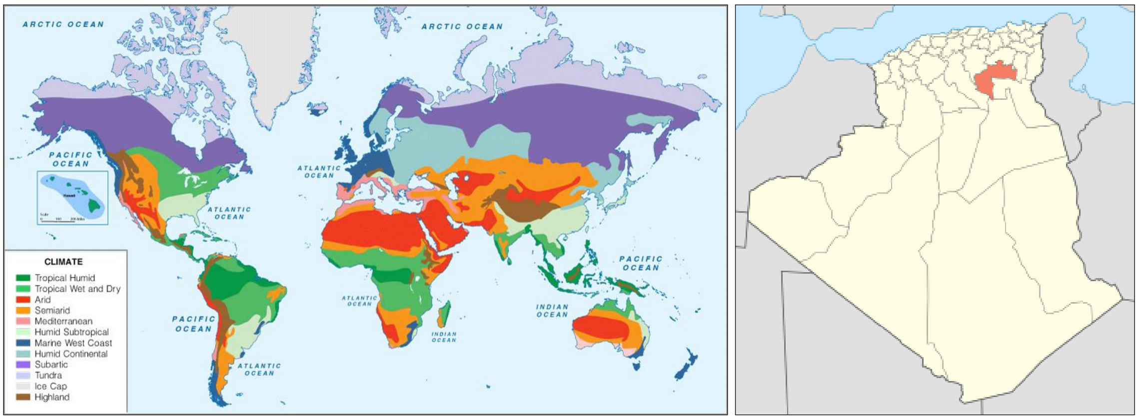


Figure 4. The climatic zone and the geographic position of the city of Biskra

Table.1: The Metrological characteristics of Biskra

Temperature (c°)	**Relative Humidity (%)**	**Precipitations (mm)**	**Winds (m/s)**
Max Temp: 42 °C in July. Min Temp: 7 °C in January. Average annual Temp: 21.5°C	Max RH: 50% Min RH: 10% Average annual RH: 46%	Very low rainfall Max: 20 mm/year Average annual 8.8 mm / year	prevailing winds are north-western in winter south-eastern in summer speed of 6 m/s to 10 m/s

3.2 The chosen buildings:

The buildings envelopes that were studied represent the most recurrent and typical envelope (walls, roofs and insulations) types of residential houses and apartments in the city of Biskra. Only the opaque parts of the building envelope were chosen since they are responsible for the majority of heat transfer from the outdoor to the indoor. In this study, different measurements of the temperature and humidity in indoor and outdoor were conducted in three typical rooms in three residential buildings

Case 1: a double brick wall with an air cavity (10cm brick+5 cm air +15cm brick)

Case 2: a double brick wall with polystyrene insulation (10cm brick+5 cm insulation +15cm brick)

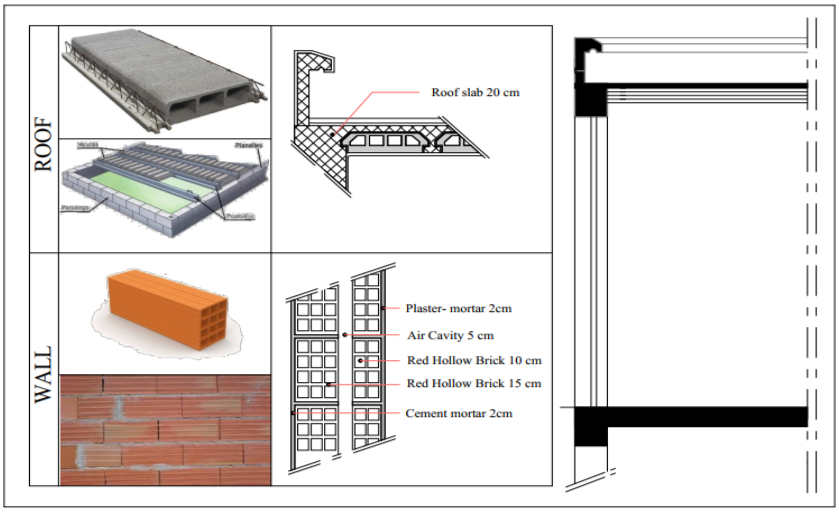
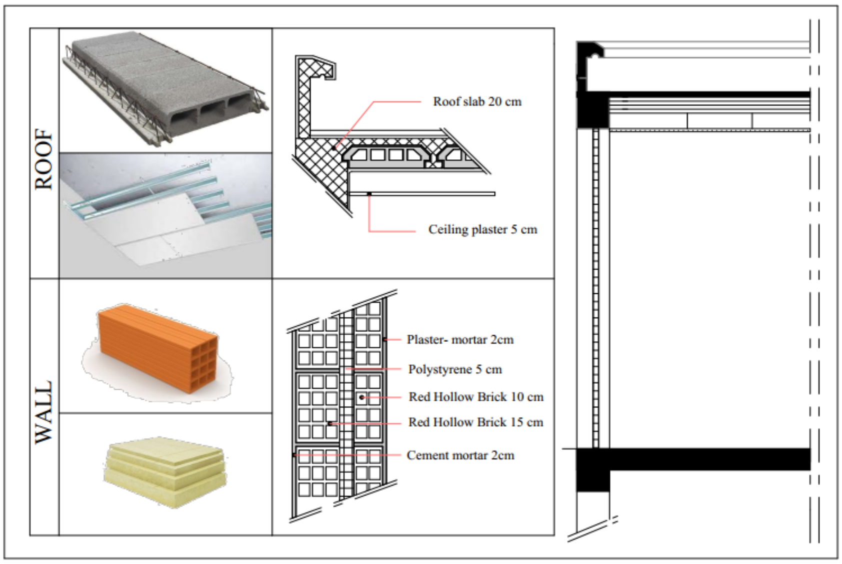
Case3: a single full perpend brick wall 20 cm

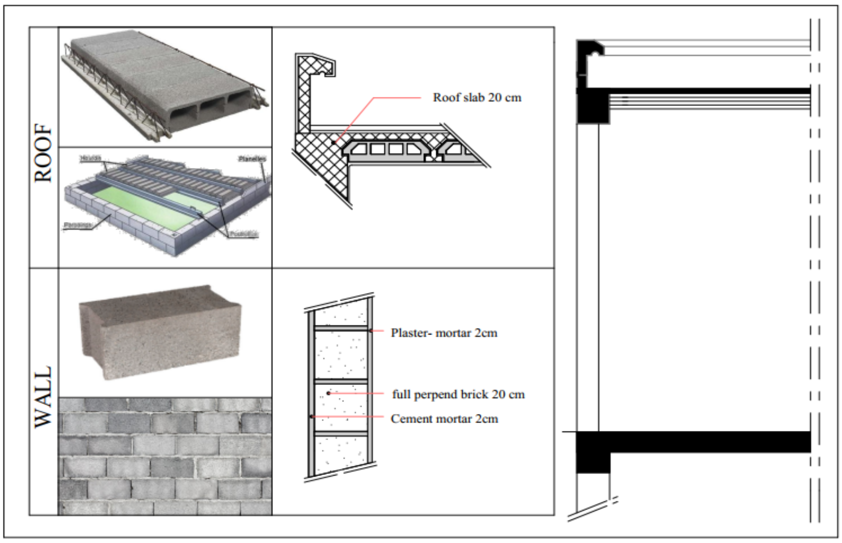
Table 2. Thermal properties of the chosen building envelope

Materials	**Thermal conductivity (W/m.k)**	**Specific heat** *(j /KG.K)*	**Dancité** *D (Kg/m3)*	**Thickness** *T (cm)*
Revetments Materials				
Cement mortar	0.80	1000	1900	0.2
Plaster mortar	0.57	1008	1150	0.2
Envelope (wall materials)				
Red Hollow brick	0.39	1000	1200	10-15
Full Cinder block	0.95	1080	975	20

Envelope (Roof materials)				
Hollow body	1.2	1008	2150	16
Compression slab	1,56	1008	2150	04
Floated slab	1,56	1008	2150	10
Envelope insulations				
Air	0.047	1000	1	5
polystyrene	0.038	1450	16-20	5

Table 3. The chosen buildings envelope compositions

Case	Envelope compositions
<u>Case 1:</u> *<u>Roof:</u>* Hollow Slab 20cm *<u>Wall:</u>* Double red brick wall Oriented: Est in the ground floor	
<u>Case 2:</u> *<u>Roof:</u>* Slab 20cm+ plaster suspending ceiling *<u>Wall:</u>* Double red brick wall+ polystyrene insulation 5 cm Oriented: Est in the first floor	

<u>Case 3:</u> *<u>Roof:</u>* hollow Slab 20cm *<u>Wall:</u>* Single prepend wall cinder block 20 cm Oriented: west on the first floor	

4. Material and Methods

In this study, a quantitative method was conducted to evaluate indoor thermal conditions using in situ measurements and numerical simulations

4.1 The measurements protocol:

In situ measurement was conducted; indoor and outdoor measurement of air temperature, relative humidity, and surface temperature, using a hygrothermal instrument Testo 480 as shown in figure 5

Figure 5. The Measuring instrument TESTO 480

The measures of the ambient and surface temperature and the relative humidity were conducted in surfaces of a wall inside and outside surface as shown in figure 6.

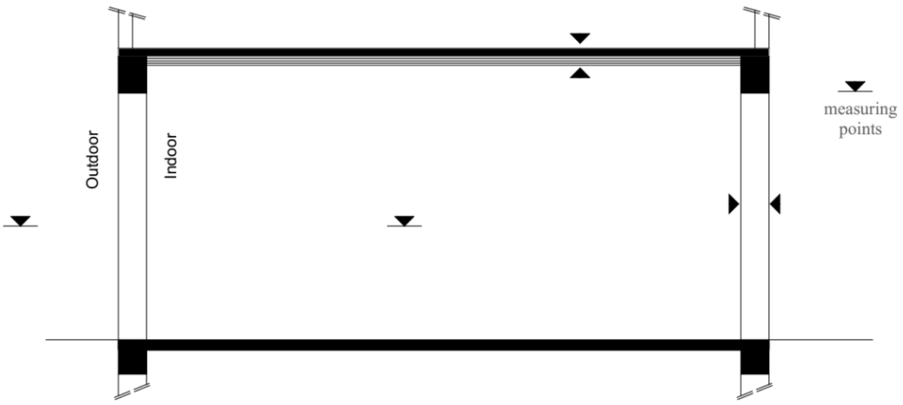


Figure 6. The Measuring positions

Bi hourly measurements were made under natural conditions without any type of active systems from (8.00 am to 22.00 pm) in a single day the 28th of March (a mild day)

4.2 The simulation protocol

In order to evaluate the thermal comfort, a numerical simulation was conducted with "DesignBuilder 5.5" software. DesignBuilder is a tool for dynamic thermal simulation and energy consumption analysis of buildings. The model of the studied Buildings and envelope compositions simulated with DesignBuilder based on actual weather conditions (climatic weather data file).

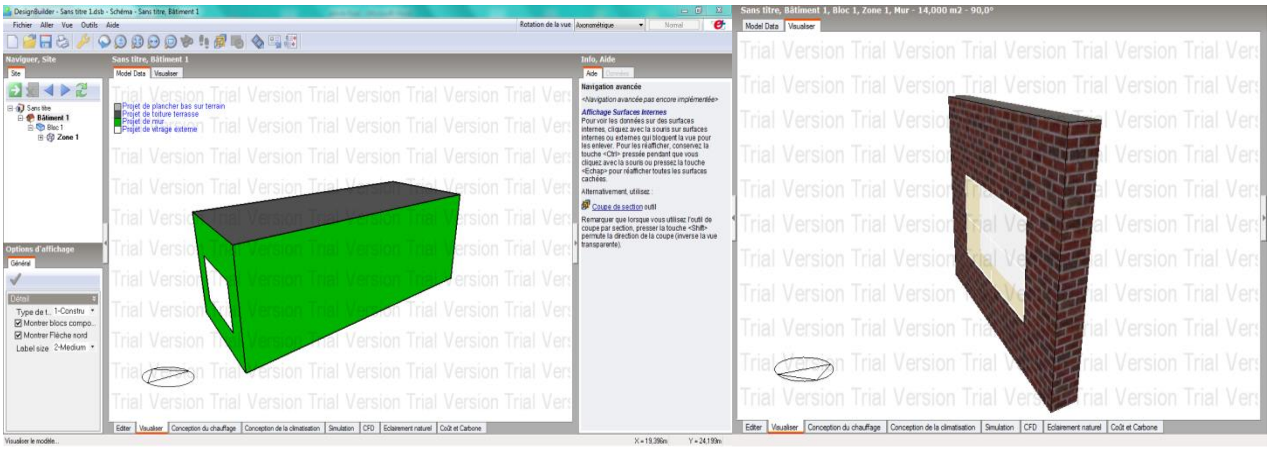


Figure 7. DesignBuilder interface

-An annual simulation was conducted

-The simulation was conducted natural conditions the mechanical systems were inactive (ventilation, air conditioning.

-Ambient and operative temperature simulation were conducted

-Three cases of the building were modeled and simulated (envelope and materials)

5. Results and discussion

5.1. Measurement results

The Ambient Temperature (Ta)

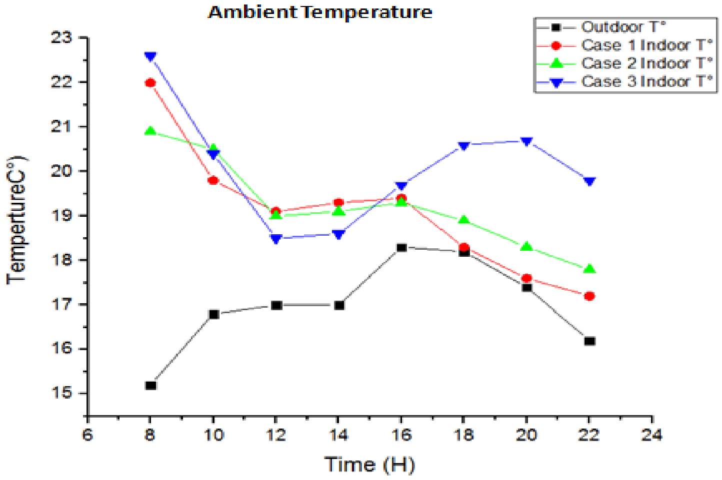


Figure 8. The ambient Temperature measured in the 3 cases

The graph Figure 8, shows the results of the measured ambient air temperature inside the 3 cases We notice that in the same outdoor temperature condition there is different indoor temperature this is due to the different envelope compositions , thickness and thermal properties ,in case 1 and 2 where the walls are thicker and more resistant we noticed that the indoor temperature (Ta) is more stable with a gap of 4 C° than case 3. The indoor ambient temperature is higher than the outdoor air temperature; this is due to the cumulative heat throughout the day and the high thermal mass of the used wall materials that keep the heat accumulated.

Wall surface temperature (radiant temperature)

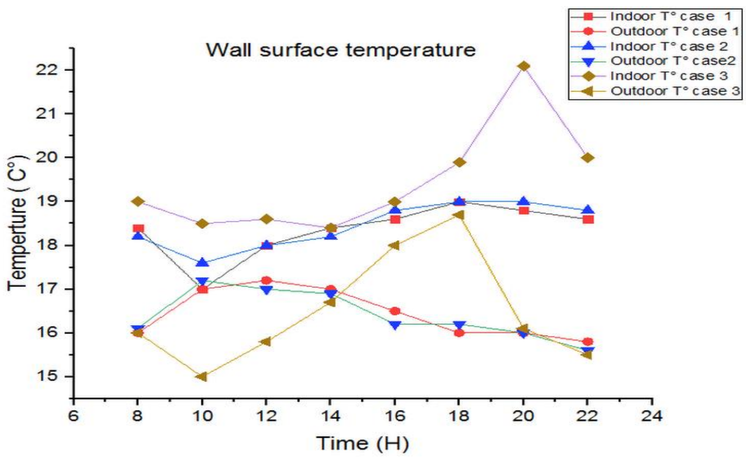


Figure 9. The wall surface (Ts) Temperature measured in the 3 cases

The graph shows the results of the measured indoor and outdoor wall surfaces temperatures of the 3 cases. As it noticed from the graph, in case 1 and 2 the indoor surface temperatures are close and almost stable throughout the day with an average lag of 3 C° due to the effect of thermal inertia.
The external surface temperature depends directly on the sun exposure and radiation, as a result, the internal surface temperature depends on the wall compositions materials and their thermal properties to conduct, accumulate and resist witch influence the indoor ambient temperatures. Thus the heat grained by the walls is stored inside the various layers of the envelope.

Roof surface temperature (radiant temperature)

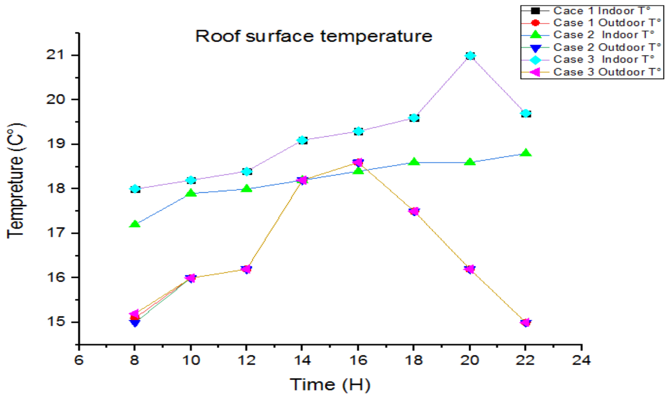


Figure 10. The Roof surface (Ts) Temperature measured in the 3 cases

The graph in Figure 10 shows the results of the measured indoor and outdoor roof surfaces temperatures of the 3 cases. The difference is between case 1and 3 with a standard roof cement slab en hollow bricks 20cm and case 2 with a plaster suspended ceiling from the result we can notice that adding the suspended plaster ceiling helps on reducing heat transfer from the outside to the inside ambiance

5.2. Simulation results

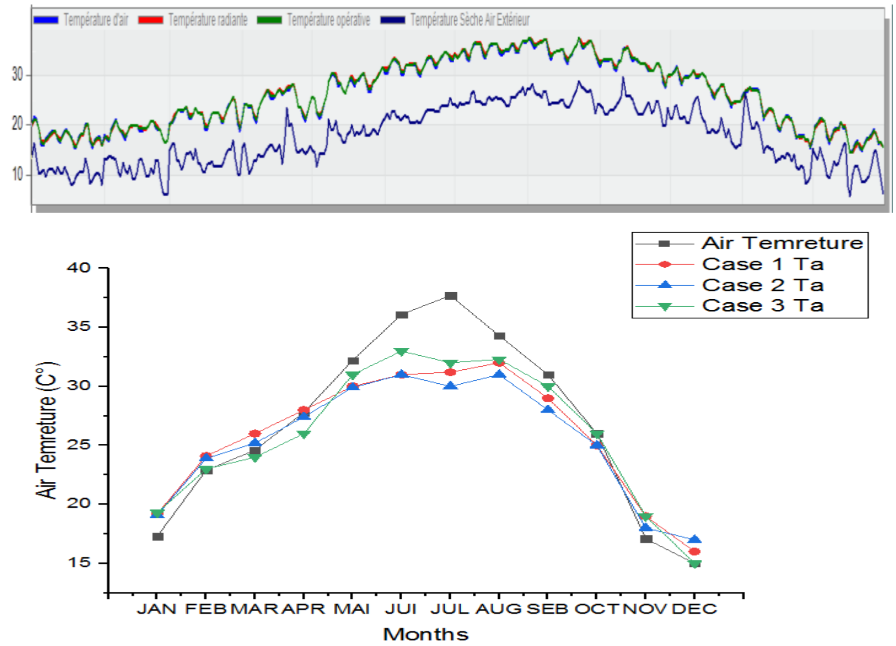


Figure 11. Simulation results of Temperature measured in the 3 cases

From the simulation results, we can notice that different envelope materials result in the different ambiance and surface temperature which means the building envelope effect directly the indoor thermal ambiance sensation that affect energy consumption.

6. Conclusion

This study shows the impact of building envelope on indoor thermal comfort which is evaluated by ambient and surface radiant temperature with different envelope building materials in a hot and dry climatic context of the city of Biskra .the study demonstrates the essential results of an empirical study that have been done using in situ measurements as well as numerical simulations, also it reveals the importance of the building wall configuration. To achieve a better thermal performance of the envelope, it is desirable to have a multi-layered envelope comprising materials of different thermo-physical properties which allow regulating heat exchanges between the building and its environment, a double red brick wall with isolation is efficient to ensure thermal comfort due to his thermo-physical properties, thus A bad choice of the material constituting the building envelope can result in a long-term additional cost to ensure thermal comfort.

In general, the study has shown that choosing a multilayered isolated envelope will likely affect positively the level of the indoor thermal comfort.

References

American Society of Heating, Refrigerating and Air-Conditioning Engineers (Ed.). (2012). *Thermal guidelines for data processing environments* (3rd ed). Atlanta, GA: ASHRAE. https://ecoinfo.cnrs.fr/IMG/pdf/ashrae_2011_thermal_guidelines_data_center.pdf

APRUE, (2015). Final energy consumption of Algeria, key figure-year 2015; Ministry of Energy and Mine https://portail.cder.dz/IMG/pdf/Renewable_Energy_and_Energy_Efficiency_Alg erian Program_EN.pdf

Bakhlah, M. S. O. (2015.). *Building Envelope Design For Indoor Air Temperature in Hot and Dry Climate,Yemen*. 57. http://eprints.usm.my/30081/1/BUILDING_ENVELOPE_DESIGN_FOR_INDOOR_AIR_TEMPERATURE.pdf

Balaji, N., Mani, M., & Venkatarama Reddy, B. (2013). *Thermal performance of the building walls*. Presented at the Building Simulation Application BSA 2013, 1st IBPSA, Italy conference Bozen-Bolzano. https://www.researchgate.net/profile/Nallaval_Balaji2/publication/235328176_Thermal_Performance_of_the_Building_Walls/links/00b49519c6633c41f7000000.pdf

Bellahcene, L., Cheknane, A., Bekkouche, Sma., & Sahel, D. (2017). The effect of the thermal inertia on the thermal transfer in building wall. *E3S Web of Conferences*, *22*, 00013. https://doi.org/10.1051/e3sconf/20172200013

Frontczak, M., Danmarks Tekniske Universitet, & DTU Byg. (2011). *Human comfort and self-estimated performance in relation to indoor environmental parameters and building features: Ph. D. thesis*. Lyngby: DTU Civil Engineering, Technical University of Denmark. https://doi:10.1016/j.buildenv.2010.10.021

Gezer, N.A. (2003).The Effects of Construction Materials On Thermal Comfort In Residential Buildings; an Analysis Using Ecotect 5.0(Doctoral dissertation, METU). https://www.academia.edu/11953883/THE_EFFECTS_OF_CONSTRUCTION_MATERIALS_ON_THERMAL_COMFORT_IN_RESIDENTIAL_BUILDINGS_AN_ANALYSIS_USING_ECOTECT_5.0

Givoni, B. (1978) L’homme l’architecture et le climat. Editions Le Moniteur, Paris, France.

Khadraoui, & Sriti, L. (2018). *The impact of facade materials on the thermal comfort and energy efficiency of offices buildings*. https://www.researchgate.net/publication/326225738_The_impact_of_facade_materials_on_the_thermal_comfort_and_energy_efficiency_of_offices_buildings

Kolokotsa, D., Diakaki, C., Grigoroudis, E., Stavrakakis, G., & Kalaitzakis, K. (2009). Decision support methodologies on the energy efficiency and energy management in buildings. *Advances in Building Energy Research*, *3*(1), 121–146. https://doi.org/10.3763/aber.2009.0305

Latreche Sihem, & Sriti Leila. (2018). The Effect Of Building Materials Choice On The Thermal Comfort In The Auto-Produced Individual Housing In Biskra. *Zenodo*. https://doi.org/10.5281/zenodo.1165204

Ould-Henia, A. (2003) .Climatic and construction choices, arid and semi-arid zones: the courtyard house of Boussaâda (in frensh) Doctoral dissertation, Federal Institute of Technology Lausanne ,Swiss.

Thiers, S., & Peuportier, B. (2008). Thermal and environmental assessment of a passive building equipped with an earth-to-air heat exchanger in France. *Solar Energy*, *82*(9), 820–831. https://doi.org/10.1016/j.solener.2008.02.014

Yang, L., Lam, J. C., & Tsang, C. L. (2008). Energy performance of building envelopes in different climate zones in China. *Applied Energy*, *85*(9), 800–817. https://doi.org/10.1016/j.apenergy.2007.11.002

Yang, L., Yan, H., & Lam, J. C. (2014). Thermal comfort and building energy consumption implications – A review. *Applied Energy*, *115*, 164–173. https://doi.org/10.1016/j.apenergy.2013.10.062