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The Effect of External Walls on Energy Performance of Algerian Rural Building in Different Climatic Zones

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ABSTRACT

The building sector is one of the largest consumers of resources (energy and materials). This matter is responsible for approximately 42% of the Algerian primary energy, and this number is expected to rise with population growth, especially urban expansion in rural areas. Designing a rural building that is energy efficient and compatible with the climatic conditions of the construction site is among the most promising sustainable methods to reduce energy consumption in buildings. The scope of this study is to evaluate rural building orientation, glazing system and the possibility of using two different types of rural constructions. First, ordinary walls (W1) are the most spread and commonly used and the second HEP (W1, W2) depends on Thermal insulation; one of which is represented by Polysterene and the second is the bio-composite date palm fiber available locally. This study was conducted in three main dominant climates in Algeria. To this end, various numerical investigations in EnergyPlussofware were performed. The results showed the effect of different climatic zones on the orientation of the building. The best orientation of the rural building in Algiers, Batna and Tamanrasset is respectively south, north and east, with the small windows of 20% window-to-wall ratio in Algiers and Tamanrasset compatibility energy saving 27.3 % and 18.3 %. The results prove the effectiveness of the wall W3, which contains bio-composite DPF, in the three climates, in Algiers, Batna, and Tamanrasset, reducing the annual total thermal energy by about 45%, 20%, and 5%, respectively. On the other hand, in Batna, the window-to-wall ratio is the best for windows of medium size, 30% to 40%.

1.Introduction

Based on recent data provided by the International Energy Agency (IEA), the building sector is accountable for roughly 40% of the total worldwide energy usage, positioning it as one of the top three sectors for energy consumption [1-3].This can be exemplified in the European Union, where the building sector is responsible for 40% of final domestic consumption [4].Studies show that in recent times, building energy consumption in Malaysia has been on an increasing trajectory as the country's economic continue to grow [5]. Similarly, in Algeria, the building sector, which comprises

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residential 35% and tertiary sectors 6%, constitutes 41% of final energy consumption [6-8].The utilization of fossil fuels to meet this substantial energy demand is unsustainable due to the risk of depletion. Consequently, transitioning towards clean and sustainable building practices is seen as a promising solution to reduce energy consumption, especially with the increasing population growth and urbanization in rural areas.

Over the past few years, the development of rural housing has been prioritized by Algerian authorities. A program to construct one million housing units was launched in 2005-2009 with almost half of the program's focus (450,000 units) allocated to housing in rural areas. This was aimed at retaining rural populations and encouraging their return from urban areas[9,10]. However, the energy performance level of these houses is very low, resulting in a significant increase in energy consumption since they were built without taking into account the climatic conditions and required thermal performance levels. Unfortunately, the Algerian state's housing interests were not considered in the 1997 residential building thermal regulation, which includes three Regulatory Technical Documents (DTR.C3-2, DTR.C3-3, and DTR.C3-4)that could save 20 to 30% of energy consumption for heating and cooling homes if applied [11-13]. The Algerian state's focus on quantity rather than quality resulted in an excessive increase of 10.8% in 2012-2013, with expectations of further increases due to improving living conditions according to the study carried out by Bahria *et al.,* [13]. Energy in the housing sector is currently a pressing issueas noted by Ghedamsi*et al.,*[14]with buildings' energy use for heating and cooling accounting for 40% to 60% of the total energy consumed in residential buildings [15].

The primary objective of this study is to assess the orientation of rural buildings, the glazing system utilized, and the feasibility of using two distinct types of rural constructions. The first type, known as ordinary walls (W1), is the most prevalent and commonly used. The second type, HEP (W1, W2), is dependent on thermal insulation and consists of two variations: one made of locally available polystyrene, while the other is composed of bio-composite cement and date palm fiber. The study was conducted in Algeria's three main climatic zones.

1.1 Background

Building envelopes are a critical aspect of construction that require careful planning and attention. One approach to reducing energy consumption involves improving the thermal insulation of buildings, for which researchers have explored various methods and techniques. Several studies have investigated the use of green insulating materials made from natural resources, which are often applied to the building envelope [16-18]. The study of Asdrubali*et al.,*[19] aims to analyze the structural, thermal, acoustical and environmental properties of wooden materials for building applications, considering factors such as fire resistance and durability. Korjenic*et al.,* [20] developed insulation materials based on natural fibers and investigated their performance in buildings with plant facades and roofs, as well as their hydrothermal behaviour; including computational simulation of behaviour of the optimal hemp fiber-based material after building into a structure with plant façade. However, the use of natural insulation materials does not always result in a reduction of environmental impacts, as noted by Sierra-Pérez *et al.,*[21], due to manufacturing processes with limited technological development.

Many researchers worldwide have studied various solutions for building insulation, tailored to the specific needs and conditions of different countries. Among the researches in this field, we mention of which

i. In a study conducted by Daouas[22] in Tunisia, the optimum insulation thickness, energy savings, and payback period were determined for a typical wall structure, taking into account both cooling and heating loads. The analytical method used was based on Complex Finite Fourier Transform (CFFT), and the insulation material used was expanded polystyrene. The study revealed that the most economical orientation for the wall was south-facing, with an optimum insulation thickness identified.
ii. Ma *et al.,*[23] conducted a study to identify the primary factors that affect the energy consumption of public buildings in northern China. Their investigation involved utilizing the eQUEST building energy simulation software. The research findings revealed that the air conditioning system, lighting density, and building envelope are the key factors that significantly influence the energy consumption of such buildings.
iii. Bulus *et al.,* [24] deals with the addition of the courtyard in the design of buildings to achieve a passive standard design, in this study he looked at the difference in temperature and humidity inside the house relative to the hot and dry weather prevailing in the Nigerian region for a building that contains a courtyard and another completely enclosed. The results obtained in this study confirmed that the design of structures is effective in improving the internal thermal environment of the building.
iv. Ozel [25] carried out a research study to analyze the thermal performance and optimum insulation thickness of building walls that use different structural materials, particularly for a south-facing wall in Elazığ, Turkey, considering the local climatic conditions. The yearly cooling and heating transmission loads are calculated by using an implicit finite difference method under steady periodic conditions.
v. Mahlia *et al.,* [26] examined the impact of installing various insulation materials of optimal thickness in building walls in Maldives, particularly in terms of potential cost savings and emission reduction.
vi. Ekici *et al.,* [27] conducted a study in Turkey to calculate the optimum insulation thickness, energy savings, and payback period for different wall types made of stone, brick, and concrete in four cities located in various climatic zones, namely Antalya, Istanbul, Elazig, and Kyseri. The study used the degree day method and considered four insulation materials, namely Fiberglass, extruded polystyrene, expanded polystyrene, and polyurethane. The results indicated that the optimum insulation thickness varied between 0.2 cm and 18.6 cm used expanded polystyrene insulation material for buildings in Turkey and demonstrated that using the optimum insulation thickness led to a 46.6% decrease in energy consumption [28].
vii. According to a study conducted by Yu *et al.,*[29] the degree day method was combined with an economical P_1-P_2 model to determine the optimum insulation thickness for five different insulation materials in four cities located in the hot summer and cold winter zone of China. The study found that the optimum thickness range for the five insulation materials was 0.053-0.236m.

At the national level, it was noted that the Promotion and Rationalization of Energy Efficiency Agency (APRUE) has introduced the Energy Efficiency in Building Program (ECO BAT), aimed at achieving a 40% reduction in energy consumption mainly due to heating and air conditioning by implementing thermal insulation in buildings which ensure an optimization of indoor comfort [30]. This program is part of the National Energy Management Program, PNME 2007-2011, and APRUE has already completed the construction of 600 HPE (high energy performance) buildings in most parts of the country, with energy consumption levels ranging from 1700KWh/m^2/year in the North to 2263KWh/m^2/year in the South [8]. Thus, the focus is on developing more sustainable building materials for thermal insulation, utilizing locally available resources and relatively simple processing techniques.

A recent study by Agoudjil*et al.,*[31]has shown that date palm wood holds potential as a thermal insulation material for buildings. Algeria has an abundant supply of 18.7 million palm trees distributed across approximately 100,000 farms. The use of date palm wood in building envelopes can take three forms: as bio-composite masonry walls, insulation panels, or bio-composite mortars. This study focuses on the use of bio-composite mortars, which consist of a mixture of cement, sand, and palm date wood aggregates. These mortars were proposed after conducting studies by Benmansour *et al.,*[32].

1.2 Objective of Study

The focus of this particular study is to evaluate the energy efficiency of rural buildings in Algeria, specifically by analyzing three different wall configurations: an ordinary cement brick wall (W1), a polystyrene cement brick wall, and a bio-composite brick wall. The research aims to assess the energy savings achieved by each type of insulated wall during the building's operation stage when compared to an ordinary cement brick wall. The study was carried out in three distinct regions: a coastal zone (ZA1), a central region (ZA2), and a southern zone (ZA3). The primary objective of this study is to evaluate the efficiency of the newly developed bio-composite material in reducing annual energy consumption resulting from thermal loss or gain through walls. Additionally, this study aims to compare the performance of the bio-composite material with that of polystyrene in various climate zones across Algeria.

2. Methodology

This study involved an examination of rural buildings using the Energy-Plus 8.2 program. The building's geometry was created using googleSketchup and defined in Openstudio, which is an open-source software designed to support EnergyPlus. The simulation period was one year, and the calculation step utilized was 15 minutes. The study used the Conduction Transfer Function (CTF) to determine the value of wall heat transfer.

2.1 Climate Data

In Algeria, the climate is transitional between maritime in the north and semi-arid to arid in the middle and the south according to the Köppen classification, as noted in studies by Agoudjil*et al.,*[31] and Benmansour *et al.,* [32]. In this study, three representative sites covering three different geographical regions of Algeria have been chosen as depicted in Figure 1[33,34].The most important characteristics of the geographical location of each city are listed in Table 1 and the weather data for each location are following below

i. Algiers(Mediterranean climate ZA1)
Itis located in the coastal region, a temperate region characterized by a mild rainy winter climate with rare snowfall and warm, humid summers at a rate of 72% per year.

ii. Batna(semi-arid region ZA2)
    It is located in the highlands region characterized by a continental climate with hot and dry summers where humidity reaches 48%; and cold winters due to its height of 1025 m above sea level.
iii. Tamanrasset(Arid region ZA3)
    Itis characterised by a desert climate that is hot and dry and where humidity does not exceed 20 % throughout the year. Temperatures are very high at midday and after sunset and very low at night. The climate covers the southern part of Algeria represented in the desert, which represents 85 %of the total area of Algeria.

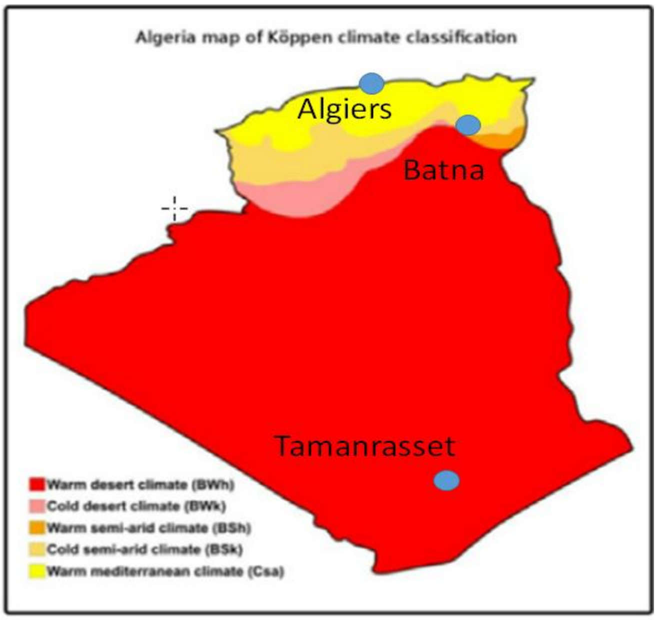
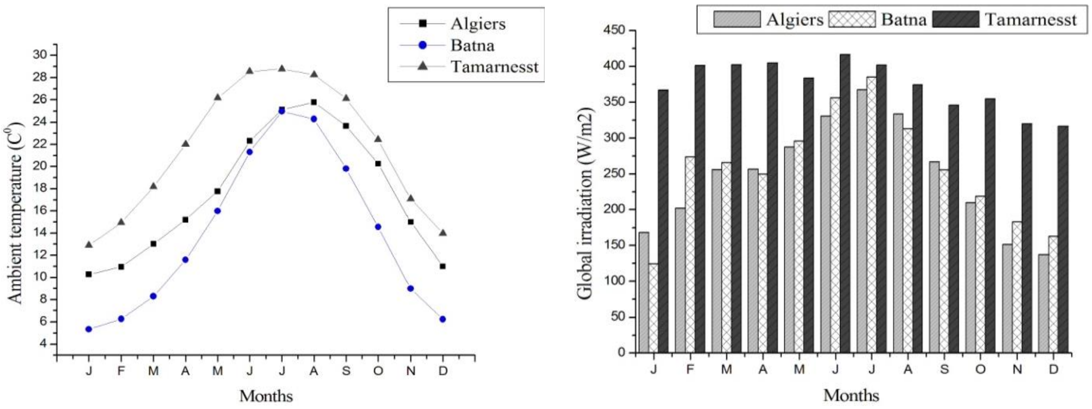


Fig. 1. Climate zones of Algeria and the selected cities in this study

The variation of the location of these cities geographically leads to a difference in global irradiations and the averagemonthly temperatures in summer and winter, as shown in Figure2. The simulation used TMY2 weather data generated by Meteonorm 7. InAlgiers we observe a slight difference in temperatures between seasons and slight fluctuations between day and night, in summer the average monthly temperature ranges between 18˚C and 25 °C, and in winter it drops to around 12°C with global irradiation ranging from 137W/m^2 in December to367 W/m^2 in August.As for the city of Batna, we recorded significant changes in temperatures between seasons, the average monthly temperatures range between 16 °C and 28 °C in summers and between 4 °C and 8 °C in winters, the lowest irradiation value recorded in January at 124 W/m^2 and the highest value in August at 385 W/m^2. Similarly, in the city of Tamanrasset, we observe very large fluctuations in temperature between day and night and the average monthly temperatures range between 26° and 30° in summer and drop to about 12 °C in winter as shown in Figure 2. The irradiation value in this region varies between 316 W/m^2 in December to 416 W/m^2 recorded in July.

Table 1
Climate zones and certain data for selected cities (Meteonorm, 2018)

Zone	City	Altitude(m)	Longitude (˚)	Latitude (°)	Tmax(°C)	Tmin (°C)	Humidity (%)
ZA1	Algiers	25	3.25	36.72	26	10	72
ZA2	Batna	1025	6.18	35.55	29	5	48
ZA3	Tamanrasset	1377	5.52	22.78	30	13	20



(a) (b)

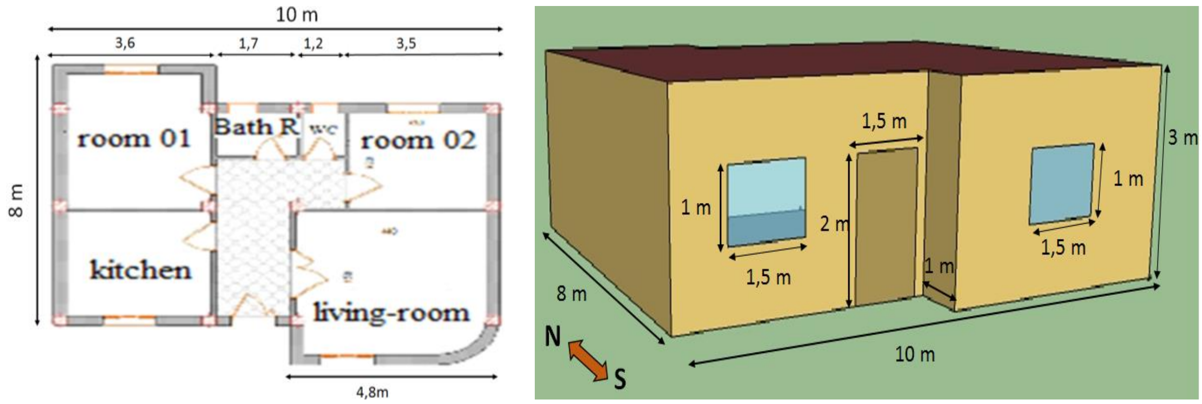
Fig. 2. Weather data in Algiers, Batna and Tamanrasset; (a)Average ambient temperature, (b) Global irradiation

2.2 Characteristics of the Studied Building

The rural building selected for this study is a single-story structure with the same characteristics as a rural building constructed by the National Centre for Studies and Research Integrated Building (CNERIB) in collaboration with the Renewable Energy Development Center (CDER) under the MED-ENEC project (Energy Efficiency in Buildings for Mediterranean Countries) [6,35]. The house has a basic layout with a floor area of 10 × 8 meters, and its longer axis runs south. Its height is about 3 meters, and it includes a living room, two bedrooms, a kitchen, a bathroom, and a toilet. On average, the house is occupied by six people.

The reference house used in this study is depicted in Figure 3, which includes one entrance on the south facade (with dimensions of 1.5 m x 2m, made of opaque timber with a thickness of 0.05m and a thermal conductivity K = 0.15 W/mK). The rural house specified in this study consists of four equally sized windows (1 × 1.5 m); they are made of clear single pane, glazing with a thickness of 0.003 m, a thermal conductivity of 0.9 W/mK and a wood frame: two of which are located on the south facade of the house, accounting for 10% of the south facade area, as shown in Figure 3. The remaining two windows are situated on the north facade, along with two smaller windows with dimensions of (0.5 × 0.7 m) for the bathroom and toilet. The glass area in this case represents 11.55% of the facade area. The total area of the windows on the exterior walls of the house is 5.56%.

In most rural houses in Algeria, the construction materials used for roofs, walls, and floors are quite similar. The roofs are made of heavy concrete and slabs, while the walls are constructed with hollow bricks and the floors are made of cement. The selection of these materials was based on (DTR. C 3-2). The roof and floor materials were automatically chosen based on the wall materials used in typical rural houses in Algeria, as shown in Table 2. The wall structure, W1, is commonly used in Algerian building construction according to (DTR. C 3-2). It is a sandwich wall made up of two layers of bricks with an air layer in between, and two cement plaster layers on both the inside and outside, as illustrated in Figure 4.



(a) (b)

Fig. 3. Geometry of the rural house studied in Algeria; (a) plan of rural building, (b) geometry realized in googleSketchup

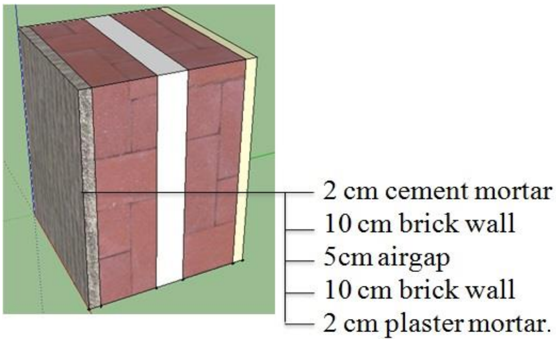


Fig. 4. The ordinary wall (W1)

Table 2 provides information on the construction and thermo-physical properties of the materials commonly used in typical rural houses in Algeria.

Table 2
Properties of materials used in calculations

Materials	ρ(kg.m^{-3})	K(W.m^{-1}.K^{-1})	Cp(J. kg^{-1}. K^{-1})	R(m^2.K. W^{-1})
Cement mortar	1908	0,80	899	/
Hollow brick	900	0,48	936	/
Air space	/	/	/	0,16
Plaster mortar	800	0,35	936	/
Bio-ciment	1293	0.14	1133.78	/
Bio-plaster	743.13	0.177	746	/
Polystyrene	15	0.043	1404	/

In order to assess how various wall configurations impact a building's energy consumption, the study programmed the air conditioning system to activate heating when the indoor temperature fell below 20 ◦C and cooling when the indoor temperature exceeded 26 °C.

2.3 Methematiqual Model

Typically, building simulation software only takes into account energy losses resulting from heat conduction through building walls. However, this paper uses the computational core of Energy Plus, which calculates energy consumption using fundamental heat balance principles. Specifically, this analysis focuses on transient heat conduction through a composite wall consisting of five parallel layers with varying materials and thicknesses, as shown in Figure 4.To model this scenario, the following assumptions are made

i. Heat transfer within the wall is unsteady and one-dimensional.
ii. The physical properties of each layer are constant.
iii. There is no heat source present within the wall.
iv. The contact between the layers of the wall is perfect.

The heat transfer through each layer of the composite wall is governed by the following heat conduction equation

$$\begin{aligned} &\frac{dT_j}{dt} = a_j.\frac{d^2T_j}{dX^2} \quad For\ l_{j-1} < x < l_j \quad j = 1,2 \dots n \\ &avec \quad a = \frac{k_j}{\rho_j.c_p} = diffusivité\ thermique\ [m^2/s] \end{aligned} \tag{1}$$

The Eq. (1) relates to the thermal behavior of materials and involves variables such as density (ρ), specific heat (Cp), temperature (T), time (t), and distance (X), as well as the thermal conductivity of the material (K). The Conduction Transfer Function (CTF) algorithm is commonly used to solve this equation for cases involving multiple materials due to its efficiency and reliability. In addition, the indoor air temperatures are regulated using the Thermal Analysis Research Program (TARP)convective heat transfer coefficient algorithm, along with specific setpoint temperatures listed in Table 3 [36]. The finite differences method was used to solve the system of equations, utilizing the Crank-Nicolson scheme.

Table 3
The common characteristics of a rural building

	Common characteristic
Floors number	1
Windows (%)	South 10.10, North 11.51, West 0, Est 0
Infiltration 1/h	0.6
Occupation rate (W/m^2)	0.7
Heating setpoint temperature (˚C)	20
Cooling setpoint temperature (˚C)	26
Specific electric gain(W/m^2)	6

2.4 Evaluation of Efficiency Action

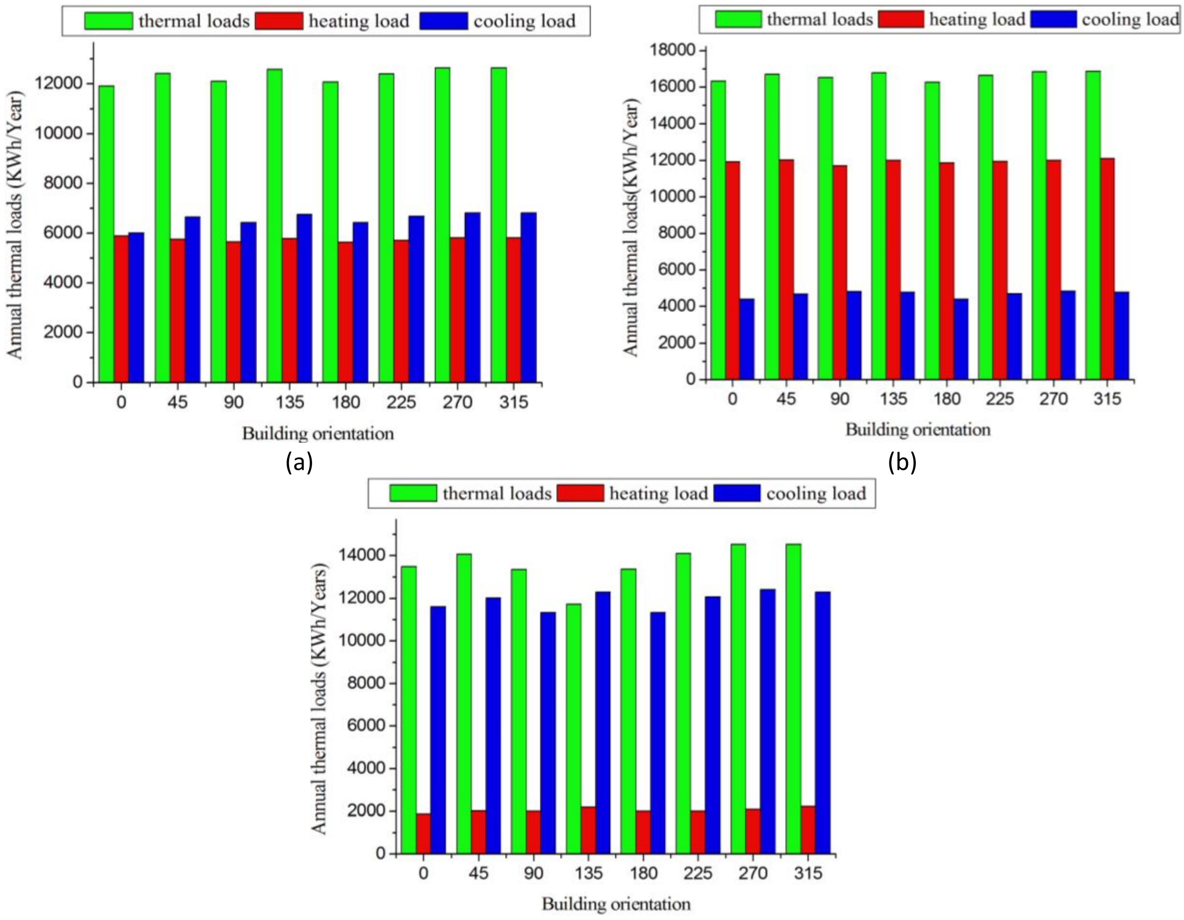
To enhance the energy efficiency of the reference house and minimize the heating and cooling requirements, a parametric investigation was conducted to identify the most suitable Energy Efficiency Measures (EEMs). The energy demands of the house were considered as the criteria to determine the optimal EEM. Various EEMs were evaluated individually and in combination to identify the most effective ones.

2.4.1 Orientation of building

The azimuth angle between true south and the front of the house determines the building's orientation. Assessing the orientation is critical since it is the initial step towards decreasing the amount of direct solar radiation that the building envelope receives on a daily basis [37]. This is particularly relevant in hot climates where cooling systems are required, especially for glass areas in the building envelope, and conversely in cold climates.

Several factors, including the climatic conditions of the construction site, building envelope material, and building height, can impact how the energy demand of a building is affected by the orientation of its external walls.

The objective of this research is to examine how building orientation impacts energy conservation while maintaining constant building features (Case 1). The building orientation is the only variable that changes, ranging from 0 degrees to 315 degrees in increments of 45 degrees counterclockwise in each scenario. The findings of the simulation conducted in three different climates in Algeria are presented in Figure5.



(a)

(b)

(c)

Fig. 5. Effect of building orientation on annual thermal loads ; (a) Case of Algiers, (b) Case of Batna, (c) Case of Tamanresset

2.4.2 Glazing system

According to Susorova*et al.,*[38] and Sim and Sim [39], the design of a building's glass facade is a crucial factor that can significantly impact its internal thermal environment. This research aims to explore the correlation between varying window-to-wall ratios and types of glazing utilized in traditional Algerian buildings.

2.4.2.1 Size of windows

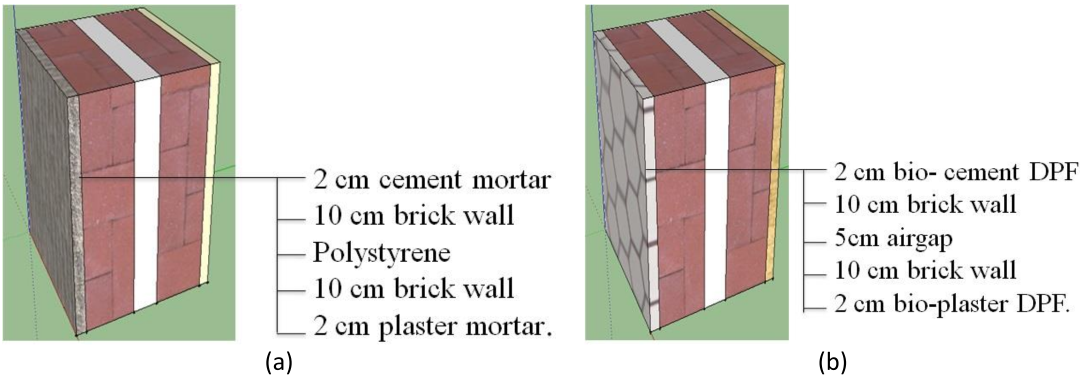
This research focuses on investigating the impact of varying window-to-wall ratios on energy performance in Algerian traditional buildings located in the temperate climatic region of Algiers. The study evaluates window performance by changing the window-to-wall ratio from 10% to 70% in 10% increments. For comparative purposes, a base case of 10% window-to-wall ratio is used, which is consistent with the experimental housing built in the Souidania region (located 20 km west of Algiers) based on the Algerian Building Code (DTR3.2 and DTR). The scope of this study is limited to traditional rural buildings with south-facing orientation, where glass areas are only present on the southern and northern facades, as previously stated.

2.4.2.2 Type of glazing

In the next stage of this section, the study focuses on examining the impact of the number of glass panels on thermal requirements while maintaining a fixed WWR of 10%. Furthermore, the research also highlights the relationship between the level of insulation and type of glass utilized by simulating two rural house models - one traditional and the other energy-efficient. For the simulations, a distance of 20mm is considered between consecutive glass panels.

2.5 Type of Thermal Insulation of Exterior Walls

Thermal insulation is widely recognized as a crucial factor in conserving energy by reducing heat transfer rates. Numerous studies have explored the impact of insulation on external walls across varying climatic conditions [27,39,40]. In this research, two different types of construction are considered for each region: Ordinary building (W1) and HEP building (W2, W3). Figure6 illustrates the use of expanded polystyrene and bio-composite made from date palm fibers as insulation materials for wall W2 and wall W3, respectively, for the different regions.The properties and thermo-physical characteristics of these materials(polystyrene, bio-cement DPF and bio-plaster DPF) are shown in Table 4.



(a) (b)

Fig. 6. Walls of HEP building; (a) Wall with polystyrene (W2), (b) Wall with bio-composite date palm fiber (W3)

Table 4
Type of exterior walls

	Ordinary building	HEP building	
Walls, U(W/m^{2}K)	W1	W2	W3
	1.237	0.552	1.018
The type of window, U(W/m^{2}K)	Clear, single	Clear, double with 20mm air gap	
	5.918	2.729	

3. Results

3.1 Effect of Orientation

The findings indicate a significant variation in the optimal building orientation for achieving optimal energy performance of the rural house envelope across the different climates studied. Specifically, for the moderate climate prevalent in the city of Algiers, the optimal building orientation was found to be facing the south (0 degrees), with the building facade directed towards this direction. This orientation allows for minimal solar radiation exposure, which in turn helps to minimize heating and cooling loads, as the climate conditions in this region tend to be closely balanced. These findings align with those reported by Gilles *et al.,* [41].

In the semi-continental climate prevalent in the city of Batna, the optimal building orientation is facing the north (180 degrees). This orientation maximizes solar radiation exposure on the glass windows, leading to a reduction in heating loads for the house compared to other orientations. In contrast, in the desert climate of Tamanrasset, cooling loads tend to be high, and it is essential to minimize solar radiation exposure to reduce the cooling loads in the house. As a result, the optimal building orientation for this region is towards the eastern side (90 degrees) or north (180 degrees) in a row, as suggested in previous studies. Choosing the optimal building orientation can lead to annual energy savings of approximately 100 to 800 KWh.

3.2 Size of Windows

Figure 7 illustrates the impact of the window-to-wall area ratio on the total heating and cooling energy for different window area values from the total south and north facades. The simulation results indicate that increasing the window area from 10% to 50% can lead to a reduction in annual heating requirements from 5708 KWh to 3411 KWh. This reduction is primarily attributed to the beneficial solar thermal gain obtained during the winter season with south-facing windows. However, beyond this threshold (50% to 70%), the heating needs of south-facing windows tend to increase with an increase in window size.

The reason for the reduction in heating requirements when increasing the window area in a house is due to the trade-off between increased solar heat gain and increased heat loss through relatively lower insulation. This finding is consistent with a previous study conducted by Missoum *et al.,* [9]. Similarly, we observed a decrease in the cooling loads of the house from 6413 to 5061 kWh with a 20% increase in the window-to-wall ratio, which is the lowest value. However, as the window area to wall ratio increases, there is a steady increase in cooling loads. This outcome can be explained by the fact that in regions with humid temperate climates, the solar heat gain through windows is beneficial for increasing heating requirements during the winter, but it contributes significantly to cooling loads during the summer.

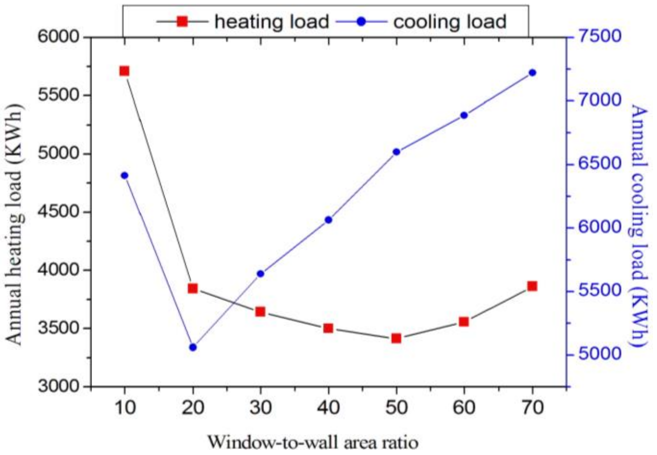


Fig. 7. The annual heating and cooling load in south façade (Algeries)

In contrast, the north facade of the house exhibits a steady increase in heating and cooling requirements as the window size increases from 10% to 70% as shown in Figure 8. Specifically, the heating requirements increase from 5708 to 6361 kWh, and the cooling requirements increase from 6413 to 6944 kWh. This finding is consistent with a study conducted by Elaouzy and Fadar[42]. The increase in heating and cooling requirements can be attributed to the large heat loss and solar radiation penetration into the building from the north facade throughout the year, which significantly affects the cooling and heating demands of the house.

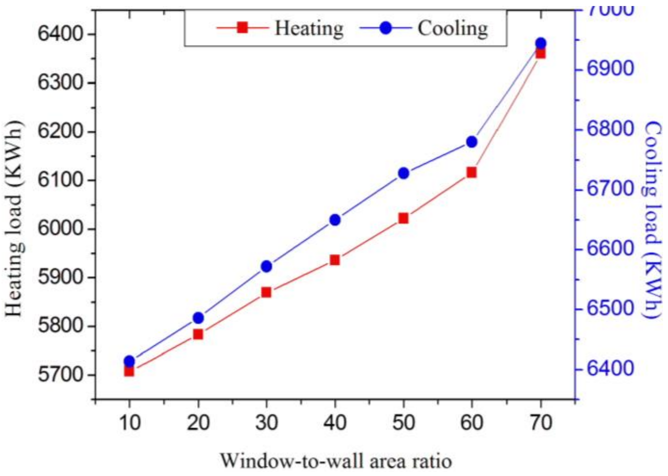
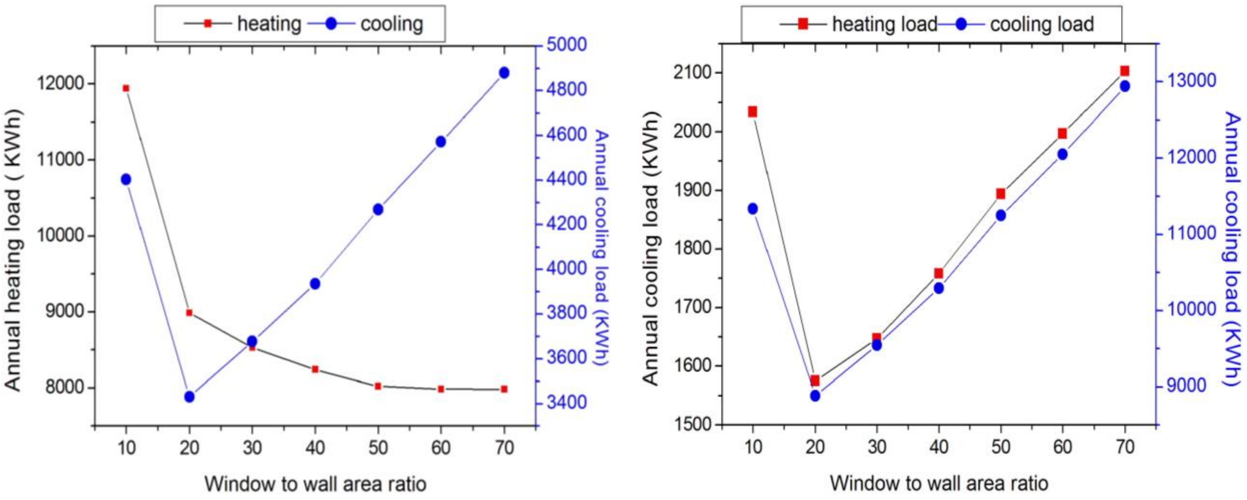


Fig. 8. The annual heating and cooling load in north façade (Algiers)

The study's results suggest that, to maximize the use of solar radiation for heating, it is advisable to increase the window area on the southern facade up to 40% of the total facade area. Additionally, to reduce solar radiation penetration during the summer, shading system could be implemented. On the other hand, for the northern facade, it is recommended to have a minimum window area of 10%.

The window-to-wall ratio has a significant impact on the total thermal energy consumed by rural buildings in Batna and Tamanrasset, particularly on the southern façade. Figure 9 demonstrates an inverse proportionality between the annual heating loads for the city of Batna and the window-to-wall ratio. The heating loads decrease from 12,000 KWh for a 10% window-to-wall ratio to approximately 8,000 KWh for window-to-wall ratios of 50%, 60%, and 70%. As for the annual cooling loads, the lowest value of 3,430 KWh corresponds to a 20% window-to-wall ratio, which aligns with the results observed in the capital city of Algiers, as mentioned previously. The same observation is noted in Figure 9(b), which represents the results of the city of Tamanrasset. The heating loads are minimized with a 20% window-to-wall ratio and continuously increase with higher window-to-wall ratios. This is primarily due to the prevailing desert climate in this region, where it is advised to use small windows that minimize solar heat gains, especially during the summer season. In contrast, in Batna, which is considered the coldest region in this study, medium-sized windows ranging from 40% to 50% of the window-to-wall ratio are considered optimal.



(a) (b)

Fig. 9. The annual heating and cooling loads in south façade; (a) Case of Batna, (b) Case of Tamanrasset

3.3 Type of Glazing

The findings presented in Table 5 demonstrate the effectiveness of double glazing, particularly in HEP buildings as compared to conventional buildings. The use of double-glazing systems leads to a reduction in the annual thermal loads demand when compared to simple glazing, particularly in cities such as Algiers and Batna, where the thermal energy requirements decrease by 3.5% and 5.1%, respectively. This reduction in energy consumption can be attributed to the thermal insulation benefits provided by the mitigation of solar heat gains/losses, resulting in reduced heating/cooling loads. However, the impact of double glazing on heat loads in Tamanrasset was found to be minimal in comparison to simple glazing.

However, we found that the impact of double glazing on the thermal loads in Tamanrasset leads to a very small increase in annual thermal loads compared to single glazing, as illustrated in Table 5 below. We observed an increase of 8 KWh, which corresponds to a mere 0.0005% increase for the ordinary construction. As for energy-efficient construction, we recorded an increase of 27 KWh for wall W2 and 23 KWh for wall W3, representing an approximate increase of 0.002% for both, which demonstrates the ineffectiveness of using double glazing in hot and dry regions. These results are consistent with previous studies conducted by Elaouzyand Fadar[42].

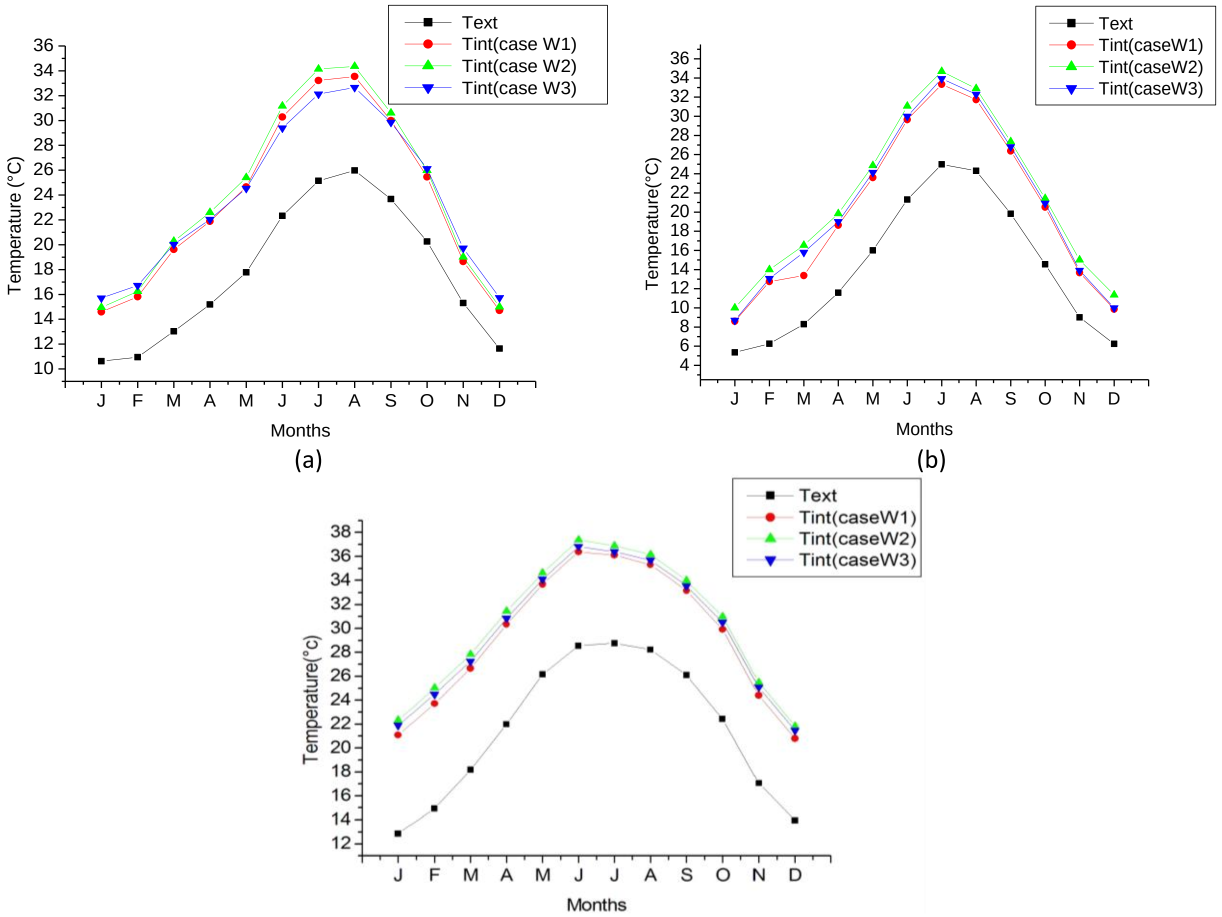
Table 5
Thermal energy loads in Algiers and Batna for type of glazing

Algiers	Ordinary	HEP	
	W1	W2	W3
Simple clear	12011KWh	11361KWh	7864 KWh
Double clear	11975KWh	10972KWh	7613 KWh
Energy saving	1.2%	3.4%	3.5%
Batna	Ordinary	HEP	
	W1	W2	W3
Simple clear	16344KWh	12761 KWh	15750 KWh
Double clear	16027KWh	12103 KWh	15189 KWh
Energy saving	1.9%	5.1%	3.7%
Tamanresset	Ordinary	HEP	
	W1	W2	W3
Simple clear	13370 KWh	12717 KWh	13180 KWh
Double clear	13378 KWh	12744 KWh	13203 KWh

3.4 Type of Thermal Insulation of Exterior Walls

The proper selection of wall insulation material is crucial for the successful implementation of thermal insulation techniques. This research aims to investigate how the characteristics of the external walls, which incorporate a new bio-composite material called ciment date palm fiber, impactthe annual thermal energy reduction resulting from thermal loss or gain through walls of a rural building constructed in the prevailing climatic conditions of the site. The study compares the energy performance of a rural building that integrates ciment date palm fibers in its external walls with a regular rural building and an energy-efficient rural building that utilizes polystyrene as an insulation material (constructed as part of an experimental project in Sudania, west of Algiers). The assessment was conducted in three distinct climates found in Algeria, namely Algiers, Batna, and Tamanrasset. First of all, before determining the energy needs of the rural building and in order to verify the effect of the type of materials used in the exterior's walls on the internal thermal conditions of the building without any thermoregulation, we ran the simulation on a rural building with no heating or cooling.The results obtained are illustrated in Figure 10 representing the monthly average temperature changes of the various exteriors walls compositions in the three previously defined climatic zones.

Through Figure 10, we notice that the composition of the exteriors walls of the building envelope plays an important role in improving the internal thermal environment of a house and its variation from one region to another. In Figure (10(a)), it is clear that the use of a wall containing palm fibers (W3) in the wetlands (Algeria) contributes to improving the internal thermal environment by about 2 °C to 3 °C compared to the use of a normal wall (W1) and a wall containing polystyrene (W2) respectively, and vice versa in winter. Improving the internal thermal environment of a building constructed with exteriors walls containing palm fibers allows reducing our annual energy needs. For the city of Batna (Figure 10(b)) the wall containing polystyrene (W2) allows the internal thermal environment to be modified by about 2 °C in winter compared to W1 and W2. While in the summer, the use of this type of wall contributes to raising temperatures, which negatively affects our energy needs used for cooling. As for Tamanrasset, we notice a convergence in temperatures for the various external wall installations, as shown in Figure (10(c)).



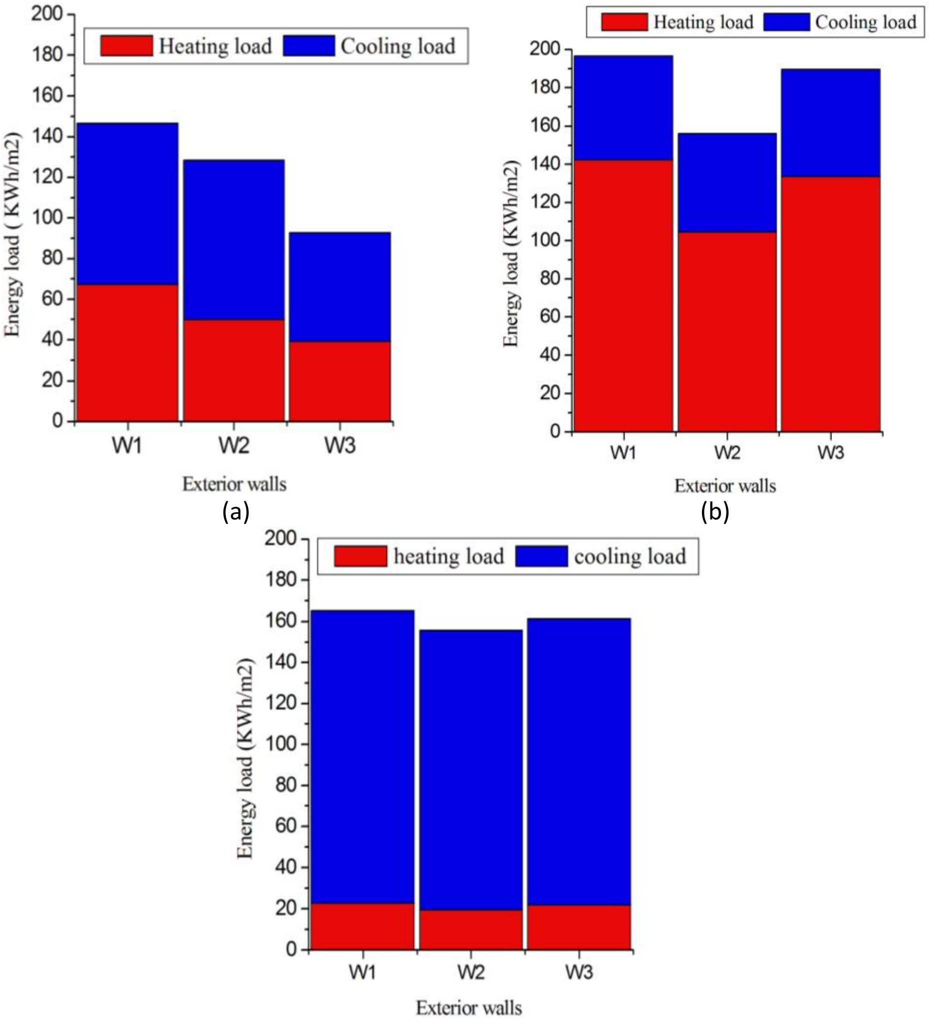
(a) (b)

(c)

Fig. 10. Average of internal and external temperature of deferent type of exteriors wall for an unconditioned rural building; (a) Case (Algiers), (b) Case (Batna), (c) Case (Tamanrasset)

To study the effect of the thermal behavior of the various external wall structures mentioned above on the energy consumed by a rural house adjusting its adaptation to works for heatingwhen the internal temperature drops below 20 °C and for cooling when the internal temperaturerises above 26 °C. The various results obtained are shown in Figure 11.

Figure 11 illustrates the total annual energy consumption for cooling and heating in both an energy-efficient building and a traditional building in the selected climates. The findings show that Batna is the coldest region among the three climates due to its high altitude (1025 m). The heating loads are dominant in this region, with a recorded heating load of 142 KWh/m^2 for a regular rural building (W1), 104 KWh/m^2 for a building that integrates polystyrene (W2) in its external walls, and 133 KWh/m^2 for a building that contains bio-composite ciment date palms (W3) in its external walls. On the other hand, the opposite is observed in Tamanrasset (shown in Figure 11(c)), where the cooling loads are high due to the hot and dry climatic conditions, reaching 142 KWh/m^2 for a regular building and 136 KWh/m^2 and 139 KWh/m^2 for W2 and W3, respectively.



(a) (b)

(c)

Fig. 11. The energy loads for different configuration external walls; (a) Case (Algiers), (b) case (Batna), (c) case (Tamanrasset)

In contrast, for the coastal region represented by Algiers, there is a convergence between the cooling and heating loads for the different external wall combinations (W1, W2, W3) respectively.

This study compared the use of energy-efficient wall installations (W2, W3) with the ordinary rural building (W1) recommended in the Algerian Thermal Regulation (DTR). The results showed that the effect of using external walls containing bio-composite ciment date palm fiber varies from region to region. In humid areas (Algiers) and semi-arid regions (Batna), the use of walls containing ciment date palms in a rural building reduced the total thermal energy consumed from 11879 KWh to 7528 KWh and from 15937 KWh to 15360 KWh, respectively. This corresponds to a reduction of about 36.6% and 3.7%, respectively, compared to the use of polystyrene in the walls, which reduces energy by 12.5% and 20.5% for both Algiers and Batna. This is due to the moisture storage characteristic of the date palm material, as demonstrated by Belloum*et al.,*[43]. The study showed that DPC enables more efficient humidity reduction in humid and semi-arid conditions, leading to a reduction in the internal heat content of a building, which in turn reduces energy used for heating and cooling and improves indoor air quality [44]. This study also found that the use of a wall containing a layer of cement reinforced with date palm material resulted in similar benefits.

In Tamanrasset's hot and dry climate and based on the results presented in Figure 11(c), it was observed that there is a similarity between the wall containing the diesel particulate filter (DPF) and the wall containing polystyrene. However, it was found that the use of walls reinforced with date palms resulted in a marginal reduction in the energy consumption required for cooling and heating of rural buildings, by around 2.3% compared to the wall containing polystyrene which only had a reduction of 5.6%.

According to the findings of Belloum's*et al.,* [43] study and the results presented in this paper, it can be concluded that using a wall that is reinforced with date palm insulating material in humid and semi-arid areas can be an effective solution to reduce energy consumption in buildings, particularly in rural areas. This option is especially useful as date palms are readily available locally, and can help to combat the annual increase in energy consumption in buildings[31]. Additionally, implementing this solution can contribute significantly towards achieving the energy efficiency agenda set by APRUE within the short term, which aims to rationalize energy use by 2030, as highlighted by Stambouli *et al.,*[30] and Rahmouni and Smail [33].

4. Conclusions

The main objective of this paper is to assess the energy efficiency of a rural building by analyzing the impact of the building envelope and its characteristics, such as orientation, glass façade, and installation of the external wall, on the total heat energy consumption. The study focuses on the relationship between these factors and the prevailing climatic conditions in Algeria, and aims to identify the most effective solutions for improving energy performance in rural buildings.

The research has demonstrated that considering the orientation of a building is crucial for its energy-efficient design across all climatic conditions, and identifying the best orientation for each climate is essential during the building design phase. The findings have revealed that the optimal orientation varies depending on the climate. For instance, in the humid temperate climate of Algeria, the semi-continental climate of Batna, and the desert climate of Tamanrasset, the south, north, and east directions were found to be the most suitable, respectively. Regarding the glass facade, the study's outcomes indicated that

i. Double-glazing systems are more efficient in High Energy Performance (HEP) buildings compared to regular buildings. When used in HEP buildings, double glazing reduces the total thermal energy consumption by 3.5% in comparison to its use in a regular building. This type of glazing is particularly effective in semi-continental and temperate regions, while simple glazing is sufficient for desert regions.
ii. Increasing the percentage of glass area on the southern façade from 10% to 70% has a positive effect on reducing winter heating energy consumption by capturing solar energy through the windows. However, it also contributes to an increase in cooling loads during the summer. To achieve the best results, a window-to-wall ratio of 20% is recommended. This percentage has been found to be most compatible with achieving the lowest annual thermal energy consumption in Algiers and Tamanrasset, resulting in energy savings of 27.3% and 18.3%, respectively. Conversely, increasing the glass area on the northern façade is not recommended due to the simultaneous increase in cooling and heating loads that comes with increasing window area on this side.

The dilemma of choosing appropriate thermal insulating materials that are locally available and suitable for specific climatic conditions is a current issue at the national level. This study evaluated the impact of using cement reinforced with date palms as an insulating material, due to its local availability, on the energy performance of the external walls of a rural building (W3). This wall was compared to another wall (W2) containing polystyrene, a commonly used thermal insulating material. The energy performance of both walls (W3 and W2) was evaluated relative to the normal wall included in the Algerian thermoregulation (DTR-) in three main climates in Algeria. The results showed that the effectiveness of wall W3 containing bi-composite DPF varied in the three climates. The use of this material contributed to a reduction of annual total thermal energy by about 45%, 20%, and 5% in humid temperate (Algiers), semi-continental (Batna), and desert (Tamanrasset) climates, respectively. This was mainly due to the characteristic moisture storage action of DPF.

By comparing the energy performance of walls W3 and W2, it can be concluded that DPF, especially in humid temperate regions, provides comparable thermal insulation to polystyrene. Wall W3 reduced the total energy by about 45%, while wall W2 reduced it by only 32%. Based on the completed study, it is recommended to use DPF-supported walls in semi-continental regions, particularly in temperate and humid areas, as it is considered one of the most promising sustainable solutions at the local level to reduce energy consumption in rural buildings and achieve the short-term goal set by APRUE by 2030.

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