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Effect of a Material Based on Date Palm Fibers on the Thermal Behavior of a Residential Building in the Atlantic Climate of Morocco

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Abstract: The potential of natural materials is becoming more and more important as concerns about the environmental impact and energy efficiency of the construction sector grow. Incorporating waste from fiber sub-products seems like a wise choice, in line with the circular economy model. Despite the fact that date palm materials have been extensively researched and developed for use in modern buildings, the potential of using date palm fibers has not been widely explored. This research intends to examine how date palm fibers thermal insulation affects a building's thermal efficiency in an Atlantic climate. An analysis using a numerical simulation using the TRNSYS software is conducted to determine the effect of this passive approach on cooling/heating loads and indoor comfort. This technique is measured against a hypothetical reference case of homemade traditional building materials without thermal insulation. The results show that insulation with date palm fiber materials has a significant effect on the indoor air temperature and the cooling and heating loads of the house. In comparison to the reference case, the studied house achieves better comfort conditions when thermal insulation is adopted since the indoor air temperature is increased by up to 3 °C in winter and decreased by up to 5 °C in summer. In addition, annual cooling and heating requirements can be reduced by 25% and 18%, respectively, by insulating the roof and walls with date palm fiber materials. On the other hand, it allows financial savings and a reduction in CO_2 emissions.

Keywords: date palm fibers; cooling load; heating load; thermal comfort; bio-composite material; TRNSYS; simulation modeling; building; environment; durability

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1. Introduction

At national and international level, the building sector poses considerable challenges to the three pillars of sustainable development (environmental, social, and economic). The researchers were motivated to find a solution to the issue of heat exchange between buildings and these three pillars of sustainable development [1]. According to the United Nations Environment Programme, the building sector accounts for 40% of global energy consumption and 30% of energy-related CO_2 emissions [2]. Furthermore, the building sector in Morocco is one of the most energy-intensive sectors, consuming approximately 33% of all final energy consumption [3]; additionally, this sector contributes to climate change by producing more than a third of all greenhouse gas emissions [3]. These percentages are on the rise due to urban and industrial growth, which is forcing energy utilities to expand production to keep up with rising demand. Indeed, from 2012 to 2016, the growth in Moroccan electricity demand increased from 31 TWh to 35.4 TWh, and in 2020, providers expect energy consumption to reach an estimated 40 TWh to 45 TWh, with growth rates of around 4.5–5% towards 2030 [4]. Most of this energy is used to heat and cool buildings, which both consume around 55% of the total amount of energy used in the construction sector [4] since they offer potential solutions for resolving discomfort issues and are also a major area for development.

In general, a building is a structure created by putting together building materials and giving its occupants a place to live and work. Therefore, it must satisfy their practical requirements while also giving them a certain level of thermal comfort. A building must provide the circumstances that are required and appropriate while minimizing its energy use and environmental impact. Energy efficiency has also grown to be a significant economic and environmental challenge. Morocco has created a new energy plan to reduce energy consumption while preserving thermal comfort which led to the introduction of Law 47-09 [5] with the aim of reducing energy use by 15% by 2030 [6]. In this perspective, the Moroccan Agency for Energy Efficiency (AMEE) has developed a thermal regulation in buildings (RTCM) [7], which includes the integration of an advanced and effective engineering system in accordance with current standards.

In order to achieve the thermally efficient buildings, bio-composite materials have been the subject of much scientific research in recent years. Bio-composite materials are purely natural lightweight blocks or composites based on continuous solid matrices reinforced with ecological additives. Among bio-composite materials, the fibers of the date palm are considered to be one of the most accessible natural fibers worldwide [8,9]. Indeed, Morocco ranks sixth in the world in terms of palm tree area and eleventh in terms of date production. Date palms make up 4.8% of all palm trees in the world and cover an area of approximately 50,000 ha [10].

Many researchers have been interested in the use of date palm products in building materials due to their high thermal insulation properties. In this regard, according to Abu-Jdayil et al. [11], date pit powder can be utilized as a filler in a polystyrene matrix to create insulating composites with very low density (457–630 kg/m^3) and low thermal conductivity (0.0515–0.0562 W/(m·K) at 25 °C). Similarly, Malhem et al. [12] found that reinforcing date palm fiber (DPF) with poly (β-hydroxybutyrate) reduces the thermal conductivity of composites between 0.086 and 0.112 W/(m.K) for various loadings of DPF. On the other hand, Boumhout et al. [13], dealing with the thermomechanical properties of mortar reinforced with DPF mesh, concluded that the addition of DPF mesh to mortar has a positive effect (lightening and enhancing insulation capacity). They also showed that DPF provides significant advantages in the building and construction industry through thermomechanical maps of the mesh composite of the material. In the same context, Benmansour et al. [14] developed a new insulating material composed of natural cement, sand, and DPF, and experimentally investigated its thermal and mechanical properties. The results demonstrated that adding DPF decreases the composite's thermal conductivity and compressive strength while increasing its weight. The effect of thermal insulation using the same materials in buildings was also studied in other works [15–17].

Through experiments and/or dynamic simulations using specialized software such as EnergyPlus and TRNSYS, several researchers have investigated the impact of insulation on the thermal behavior of buildings. In this context, Lamrhari et al. [18] conducted a study on an apartment named ADAM which is located in the city of Marrakech to evaluate a set of parameters on the energy and thermal performance of a building, one of the parameters studied is thermal insulation. A digital model of the apartment was developed using TRNSYS. In order to carry out a general study on all the Moroccan climatic zones, as defined by the Moroccan Agency for Energy Efficiency, they carried out dynamic thermal simulations to evaluate the impact of the studied techniques on the thermal performance and the energy saving of the considered apartment in six climates: Atlantic, Mediterranean, Continental, Cold, Semi-arid, and Desert. The authors have confirmed that buildings located in the Atlantic climate require thermal insulation to reduce energy consumption. In another studies conducted by the same tool, Mastouri et al. [19] were studying the impact of combining thermal insulation with high thermal inertia on a building's thermal performance in a hot, semi-arid area. Dynamic simulation and on-site monitoring of a two-floor detached house in Benguerir region of Marrakech (Morocco) are used to examine the effects of various passive strategies on the cooling/heating loads and indoor comfort.

On the other hand, there are other researchers who prefer to use Energy Plus to analyse the performance of buildings [20–23].

Moreover, thermal insulation is mentioned in terms of building energy efficiency so frequently that it has become synonymous with research [24]. However, high thermal insulation has a dubious effect on thermal loads, causing significant overheating in summer [25,26]. Although it cannot be ignored, this issue has not received sufficient attention. An element of the objective of this work will be the analysis of this point.

Based on the last point, this research aims to reduce energy consumption in the building sector while maintaining a satisfactory level of thermal comfort by offering new materials for thermal insulation. So, this study investigates the effect of integrating these materials and their impact on the building's design on energy efficiency; the idea here is to probe the energy performance of a two-story residential building, within which a passive technique (insulation) has been integrated, through numerical studies. The methodology is to determine, through dynamic thermal simulations using TRNSYS software, the degree of thermal comfort, energy performance, and greenhouse gas of building configurations was evaluated.

Research Significance

According to the literature review, adding fibers to earth bricks as reinforcement enables the creation of an environmentally friendly material with excellent mechanical and thermal properties. One of these fibers is the date palm fiber which is studied by several researchers as incited in the introduction section, but the evaluation of global energy performance of buildings integrating the material insulation based on these fibers has never been studied, to the author's knowledge. In this regard, the performance of these materials has been evaluated in the building located in Casablanca city. In this paper, the analysis of energy demand and the effect on thermal comfort using date palm fibers was performed based on the dynamic thermal simulation tool TRNSYS software.

2. Materials and Methods

This study aims to compare the thermal characteristics, including thermal behavior and cooling/heating energy demand of a traditional reference residential building located in Casablanca, the largest city in Morocco, with those of a house insulated with DPF materials. For this purpose, the structure of the residential building was first planned to use conventional construction materials and then using an insulating layer of DPF. An overview of the proposed methodology and the software packages used in this study is shown in Figure 1 in general. There are two simulation cases as follows:

- Scenario 1: reference house building built using regular Moroccan materials;
- Scenario 2: reference house building modified by using DPF materials for insulation.

For the analysis of thermal behavior and cooling/heating demand of the buildings, the estimation of annual energy needs of the reference building (in kWh/m^2. year) under different configurations was obtained and evaluated both in cold and hot seasons.

The transient thermal behavior of the buildings was simulated using TRNSYS software to carry out the proposed methodology. Using Type 56 (TRNBuild) with a time step of one hour, the transient multi-zone modeling was performed. The Sketch Up plug-in TRNSYS 3D was used to create the 3D geometry of the building. The simulations are executed using data from the Casablanca region's Typical Meteorological Year (TMY), which were obtained using the Meteonorm software 7.0 [27]. Since we will assess the thermal performance according to the construction thermal regulation in Morocco which uses ISO 7730 [28] in its calculations, we tend to work with the same temperature comfort range of 20–26 °C to calculate the yearly thermal loads for heating and cooling for the two configurations.

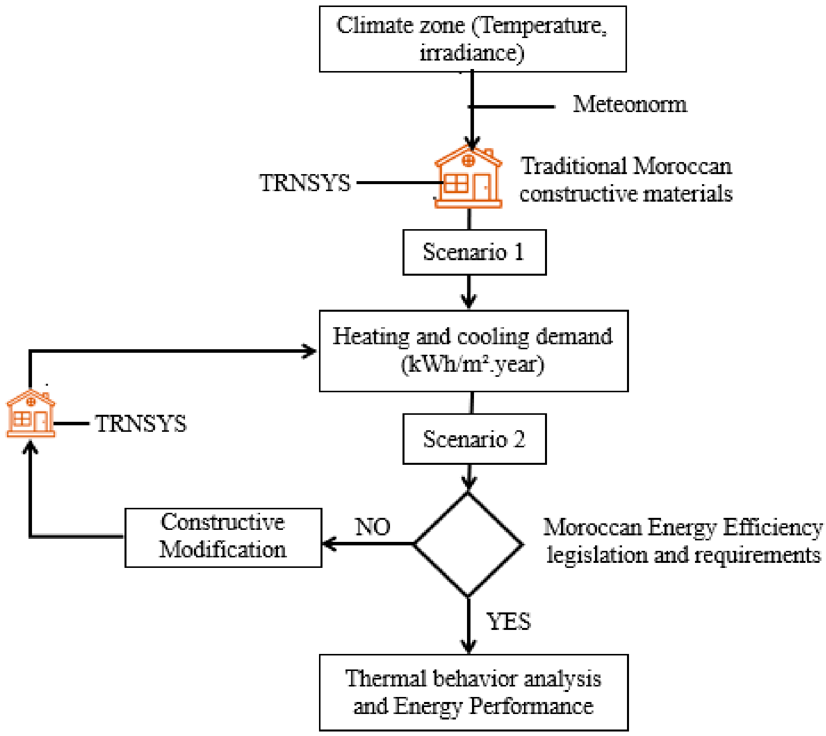
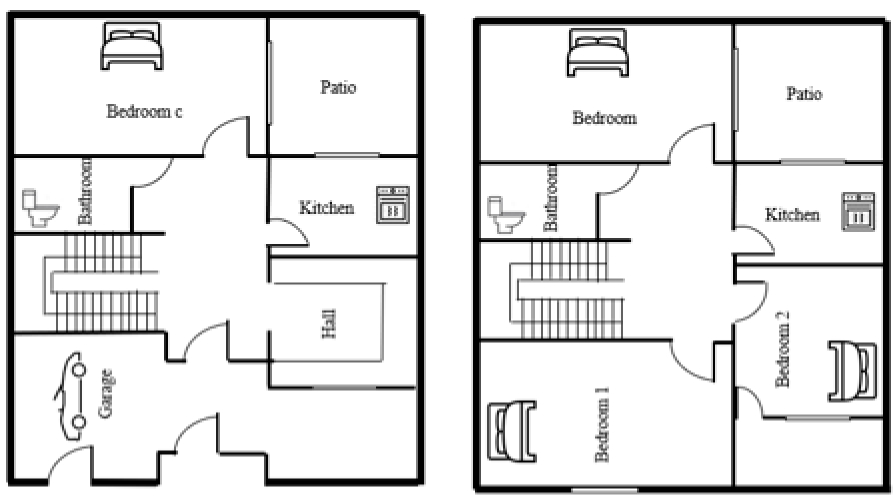


Figure 1. General description of the methodology used in this study.

2.1. Reference Residential Building

The reference building is a two-story residential building with a floor area of 130 m^2, built on slab-on-grade foundation. It is located in Casablanca, Morocco. The first floor has three bedrooms with a bathroom, kitchen, and a terrace; the ground floor has a bedroom, a kitchen, a living room, a bathroom, and a garage; the main entrance to the building is on the south side. Figure 2 depicts the distribution and general overview of the building.



(**a**) Ground floor (**b**) First floor

Figure 2. Building case study: general overview.

2.2. Context Climatic

To define the borders of the various climate types, Koppen created the first quantitative system of climate categorization in the world based on empirical evidence [29,30]. The parameters of several climate zones around the world were established by the climate characterization system using monthly temperature and precipitation data [29]. The updated digitalized Koppen–Geiger categorization system was released in 2006 [30].

In this research, we considered the thermal performance and energy saving potential of the residential structure located in a hot summer Mediterranean climate (Csa). Csa climate is characterized by warm to hot, dry summers and mild, fairly wet winters. In general, monthly temperatures in this climate exceed 22.0 °C (71.6 °F) in the warmest month and average between 18 and −3 °C in the coldest month. The city of Casablanca was the focus of the study because of its geographical location and importance in terms of population growth and economic development. Table 1 shows geographic information on the chosen city.

Table 1. Description of the studied climate (Meteonorm 2014).

Country	City	Latitude	Longitude	Elevation (m)	T_{min} (°C)	T_{moy} (°C)	T_{max} (°C)
Morocco	Casablanca	33°34′	7°35′	60	5 °C	18.31 °C	33 °C

2.3. Studied Configurations

The conventional building materials in Morocco are based on bricks, thick concrete, and cement mortar. Due to the effect of the outside environment, these buildings frequently experience uncomfortable thermal conditions. The current study's goal is to assess new insulating materials and evaluate how much of an impact they have on comfort. This was achieved by simulating two cell configurations (reference case and bioclimatic), one built with modern materials and the other with conventional materials.

The initial configuration corresponded to the studied real typical residential building, which did not include any passive technique, but relied on classical materials that are locally common in Morocco, according to recent contributions [19,31,32]. Table 2 summarizes the thermophysical characteristics of the first configuration which corresponds to Scenario 1. While, in the second configuration (Scenario 2), the walls are composed of 2 cm insulting mortar (M-DPF), and the roof is insulated by 3 cm of panel P-DPF to minimize exchange and preserve the roof's efficiency. Table 3 displays an overview of the thermophysical characteristics of the insulators.

Table 2. Reference residential building: initially constructive characteristics.

	Material	Thickness (cm)	Transmission Coefficient (W/(m^2·K))
Eternal Walls	Cement plaster	2	2.42
	Brick wall	20	
	Cement plaster	2	
Roof	Tile	1	2.48
	Mortar layer	10	
	Concert slab	16	
	Plaster	2	

Table 3. Thermal properties of insulation.

Materiel	Thickness (cm)	Thermal Conductivity (W/m·K)	Density (kg/m^3)
M-DPF	2	0.243	1217
P-DPF	3	0.033	121

Note that the M-DPF and P-DPF are two natural and ecological thermal insulators elaborated from recycled date palm waste. More details on the study of the thermophysical and mechanical properties of the M-DPF composite material and the P-DPF panel can be found in [13,33].

2.4. Simulation Models

In the present study, a building's energy efficiency was assessed utilizing transient modeling with TRNSYS software [34]. Indeed, based primarily on the ability to simulate the thermal behavior and energy performance of a building utilizing the availability of current models, comparisons between the software options were made. According to this analysis, TRNSYS and EnergyPlus appear to be the two systems that most effectively solve the issue at hand. TRNSYS has the benefits of a simpler user interface, quicker handling, and the ability to add "Types" written in Fortran or another programming language. TRNSYS is based on the nodal modeling approach, which is a great tool for simulation research.

So, the building model was created using TRNBUILD (type 56), which allowed for the entry of the necessary data to simulate the building by specifying its envelope (materials, thickness, layers, thermophysical characteristics, windows, infiltration, etc.). The transfer function method is used to resolve the system.

According to [34], the energy balance in each network node (i) is stated as follows:

$$\dot{Q}_i = \dot{Q}_{surf} + \dot{Q}_{inf} + \dot{Q}_{vent} + \dot{Q}_{g,c} + \dot{Q}_{cplg} + \dot{Q}_{solar} + \dot{Q}_{ISHCCI} \quad (1)$$

where $\dot{Q}_i$ is the global energy flow for node i, $\dot{Q}_{surf}$ is the gains from convective internal walls [W], $\dot{Q}_{inf}$ is the infiltration gains due to the air flow from outside [W], $\dot{Q}_{vent}$ is the ventilation gains led by the airflow from a defined source by the user and HVAC system) [W], and $\dot{Q}_{cplg}$ is the convective gains due to the air flow between zones [W].

These terms are given, respectively, by:

$$\dot{Q}_{surf} = UA(T_w - T_{air}); \quad (2)$$

$$\dot{Q}_{inf} = \dot{V}\rho C_p(T_{ext} - T_{air}); \quad (3)$$

$$\dot{Q}_{vent} = \dot{V}\rho C_p(T_{vent} - T_{air}); \quad (4)$$

$$\dot{Q}_{cplg} = \dot{V}\rho C_p(T_{zone} - T_{air}). \quad (5)$$

In Equation (1), $\dot{Q}_{g,c}$ is the internal convective gains by people, equipment, illumination, radiators, etc. [W], $\dot{Q}_{solar}$ is the solar gains entering a zone through external windows which are immediately transferred to convective gain in indoor air [W]. $\dot{Q}_{ISHCCI}$ is the solar radiation absorbed by the internal shading devices in the zone which are directly transferred to a convective gain in indoor air [W].

Equation (1) states that the net heat flow "$\dot{Q}_i$" exchanged by a zone determines the change in thermal energy in that zone [34]. TRNSYS uses Equation (6) to calculate the temperature of a thermal zone (thermal node) within a building, which is expressed as:

$$C_i \frac{d}{dt} T_i = \dot{Q}_i \quad (6)$$

The heat load of a building is the amount of heat that must be supplied (heating) or removed (cooling) over a given period of time to maintain a fixed temperature "set-point". This heating/cooling load is connected directly to the air temperature of the zone. Equation (6) can be then rewritten to consider the thermal power [34]:

$$C_i \frac{d}{dt} T_i = \dot{Q}_i - P_i \quad (7)$$

where P_i is the thermal power for the considered thermal zone i [W]. The value is negative for heating and positive for cooling.

Using meteorological data of Casablanca city, the building is designed in mono-zones during the course of the year, using a time interval of one hour (0–8760 h). Exchanges in convection and radiation are taken into account. The walls and roofs' outer surface absorption coefficient (α) is estimated to be 0.7, while the emissivity coefficient (ε) is estimated to be 0.9. The following relation (Equation (8)) [35], is used to compute the heat transfer coefficients by convection for internal walls and surfaces. The values of the parameters *C* and *n* for each surface are shown in Table 4.

$$H_{inside} = C\,(T_{surf} - T_{air})^n \quad (8)$$

Table 4. Parameters for calculating the heat transfer coefficient by convection.

Surface Type	C ($kJ \cdot h^{-1} \cdot m^{-2} \cdot K \cdot n^{-1}$)	N
Floor	7.20	0.31
Ceiling	3.88	0.31
Wall (vertical surface)	5.76	0.30

The following correlation, which accounts for the wind velocity V_{wind}, is used to obtain the convective heat transfer coefficient for exterior surfaces [36].

$$H_{c,outside} = 4.955 + 1.44\, V_{wind} \quad (9)$$

The residence is initially set to a temperature of 20 °C and a relative humidity of 50%. Each wall's infiltration factor is set to 0.5 ACH [37]. There is no free cooling because the doors and windows are always locked, and there is internal heat generation from lights of 5 W/m^2. Because of this, the internal gains produced by the population were measured from 6 p.m. to 8 a.m. and from 12 p.m. to 2 p.m., with the exception of weekends when they were measured constantly. This balance sheet is executed at each simulation time step to calculate the amount of energy needed to maintain a fixed-point temperature in accordance with Moroccan norms [28].

Using TRNSYS Type 77, which is based on the following Kusuda correlation, the building's ground coupling is completed.

$$T = T_{mean} - T_{amp}{}^{*}\exp\left[-\text{depth} * \left(\frac{\pi}{365\alpha}\right)^{0.5}\right]\cos\left\{\frac{2\pi}{365}\left[\text{tnow} - \text{tshift} - \frac{\text{depth}}{2} * \left(\frac{365}{\pi\alpha}\right)^{0.5}\right]\right\} \quad (10)$$

The sky temperature was determined using Type 69, which takes into account the ambient temperature, dew point temperature, and altitude above sea level.

$$T_{sky} = T_{amb}(\varepsilon_0 + 0.8\,(1 - \varepsilon_0)\,C_{cover})^{0.25} \quad (11)$$

with

$$C_{cover} = (1.4286 \times \frac{EDif}{Eglob, H} - 0.3)^{0.5}. \quad (12)$$

The emissivity of the clear sky is calculated from the saturation temperature (T_{sat}) determined by Type 33 and the meteorological data, it is expressed as follows:

$$\varepsilon_0 = 0.711 + 0.0056\, T_{sat} + 0.000073\, T_{sat}^2 + 0.013 \cos\left(2\pi \frac{time}{24}\right) + 0.00012(P_{atm} - P_0). \quad (13)$$

3. Results

3.1. Heating and Cooling Loads

According to the national energy demand specifications, an analysis and comparison of the simulation, including a reference building and a modified one, were conducted. The results for the reference house built with the construction characteristics listed in Table 2 are presented in Table 5. Based on TRNSYS software's estimation of the relevant external and indoor temperature evolution over an average year for Casablanca, Morocco (climate zone Z1, Morocco), the energy consumption of this building usage was calculated (see Figure 3).

Table 5. Heating/cooling energy demand of reference building.

	Annual Cooling/Heating Energy Demand (kWh/year)	**Averaged Cooling/Heating Energy Demand (kWh/m^2·year)**
Heating demand	3172	24.4
Cooling demand	3081	23.7
Heating and cooling demand	6253	48.1

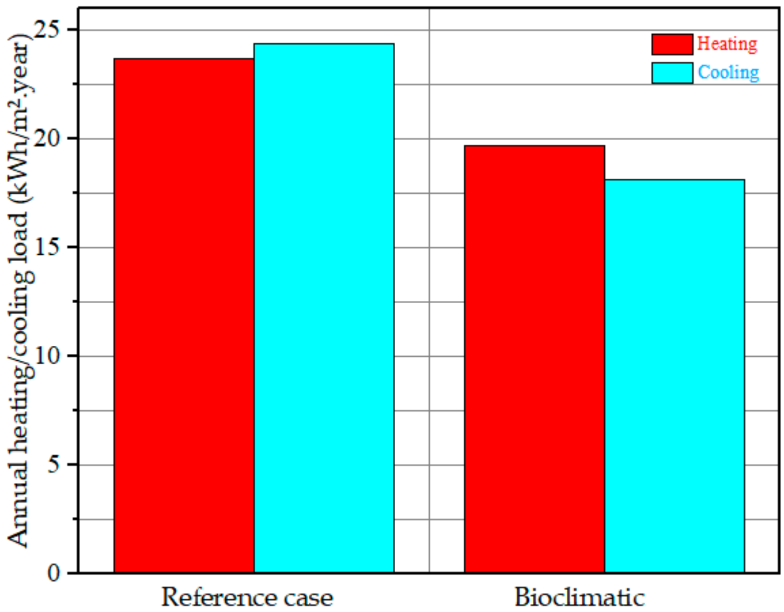


Figure 3. Heating and cooling loads for the reference case and bioclimatic configuration.

The yearly heating and cooling energy needs of the reference case are estimated at 23.7 kWh/m^2.year for heating and 24.4 kWh/m^2.year for cooling, which is 48.1 kWh/m^2·year of the annual cooling and heating energy consumption. This consumption was higher than the limit value of 40 kWh/m^2.year set by the Moroccan RTCM regulation for the Z2 climatic zone [7].

The second configuration (i.e., bioclimatic) reduced the amount of energy required for cooling and heating by 25% and 18%, respectively. Additionally, it is predicted that the second configuration's yearly heating and cooling energy requirements will be 37.8 kWh/m^2.year. When these values are compared to the Moroccan thermal regulations [7], it is clear that the bioclimatic design is mainly sufficient to satisfy zone 1 regulatory requirements.

3.2. Thermal Behavior Analysis

The thermal behavior of the house is analyzed by comparing the air temperature profiles in each level of the two configurations studied over the course of two seasons.

3.2.1. Thermal Behavior in the Winter

The months from December to February are selected to study the thermal behavior of the house in winter. The minimum outdoor temperature during these months was 5.7 °C, while the highest temperature was 24.5 °C. Figure 4B shows that the air temperature in the second configuration's ground floor varies from 12.5 °C to 20 °C, while in the reference case (Figure 4A), it varies from 9.26 °C to 22 °C. Indeed, Figure 4A shows that air temperature on the first floor varies from 12.35 °C to 20 °C in the second configuration, while in the reference case, they were 8.35 °C to 20 °C (Figure 4A).

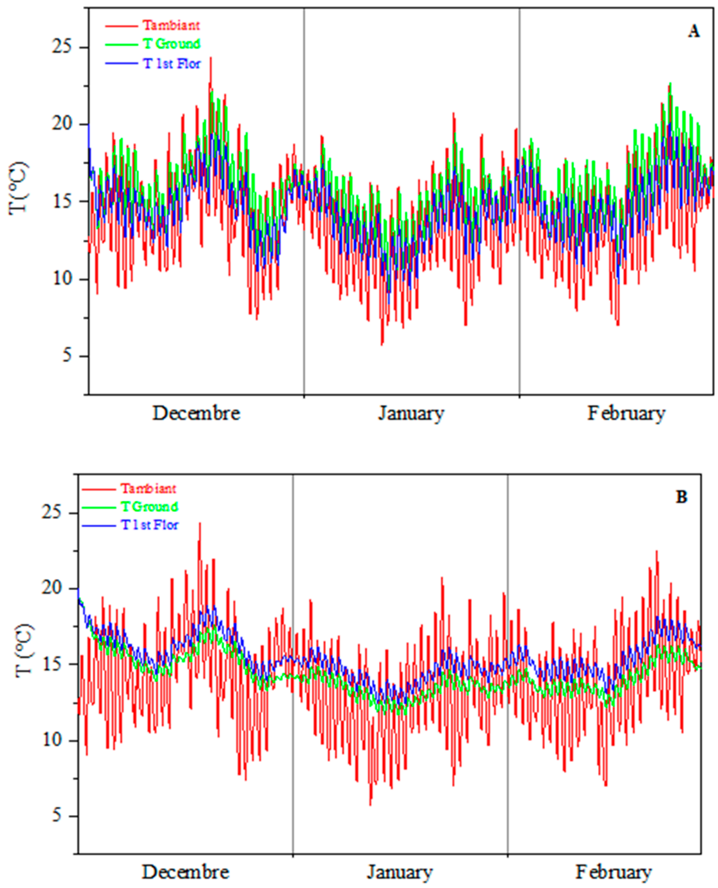


Figure 4. Air temperature hourly variation in winter for (**A**) reference case and (**B**) bioclimatic house.

Moreover, the daily air temperature amplitude obtained by peak-to-peak difference in the ground floor of the house which was insulated by DPF materials (scenario 2) was less than 1 °C. The reference case, on the other hand, had a larger amplitude as it could reach 4.7 °C (Figure 4B). The amplitude of air temperature on the first floor for the second configuration (scenario 2) is up to 1.1 °C (Figure 4B), but it may reach 4.4 °C for the reference case (Figure 4A).

Since the indoor temperature of the house does not always drop inside the range of comfort for winter, its thermal behavior during the winter season demonstrates the efficiency of the integrated passive approaches. The building's envelope's thermal insulation is a well-known method for achieving thermal comfort throughout the heating season [26].

In fact, the house is better protected from the cold than the reference case because of the thermal insulation in the walls, which raises its minimum internal temperature. This explains the consistent indoor temperatures noticed in the second configuration (scenario 2), where thermal inertia efficiently reduces fluctuations in air temperature. Nevertheless, thermal inertia alone, without the help of the thermal insulation of the envelope, might not be sufficient to generate enough thermal comfort, depending on the external climate conditions. Martin et al. raised this issue [38].

3.2.2. Thermal Behavior in the Summer

The months of June, July, and August are chosen for the analysis of the house's thermal behavior during the hot season. In these months, the average outside air temperature is 27.7 °C, reaching a maximum of 33.3 °C. As a result, the air temperature for the second configuration's ground floor (Figure 5B) is inferior to 22 °C with occasional peaks of 25 °C, but the air temperature in the reference case is generally over 25 °C and may possibly be close to 30 °C (Figure 5A). Correspondingly on the 1st floor, the air temperature for the second configuration (Scenario 2) does not surpass 23 °C on the first floor, with some peaks reaching 25.5 °C during a few days (Figure 5B); this is contrary to the reference case, where the air temperature is generally above 20 °C with peaks of 32 °C (Figure 5A). Moreover, the ground floor for the bioclimatic configuration (scenario 2) showed a daily air temperature amplitude (peak-to-peak difference) of less than 1 °C. On the other hand, the reference case had a larger amplitude since it could reach 7 °C (Figure 5B). Identical to the second configuration (scenario 2), the air temperature amplitude on the first floor is up to 1.3 °C (Figure 5B), while it may reach 7.1 °C in the reference case (Figure 5A).

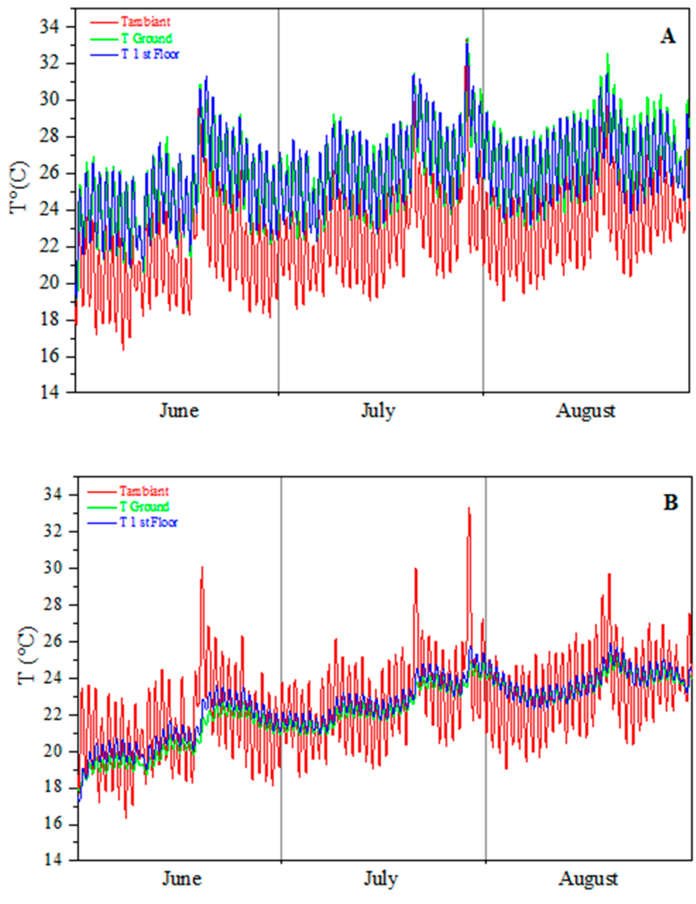


Figure 5. Air temperature hourly variation in summer for (**A**) reference case and (**B**) bioclimatic house.

It is abundantly obvious that DPF wall and roof insulation helps to stabilize indoor air temperature by reducing peak-to-peak fluctuations throughout the day. Additionally, it does excellent work for limiting the heat gain of the house in the summer. Roof insulation is a crucial factor to take into account for minimizing the energy demand in the building—as indicated by various studies in the literature [39–41]—as it prevents enormous solar radiation from penetrating the envelope.

3.3. Analysis of Greenhouse Gas (GHG) Emissions

Buildings should overcome the current energy framework and incorporate the related environmental effects, such as GHG emissions, into their design. This section details how heating and cooling affect the environment in terms of GHG emissions. Electricity was employed in this investigation for both heating and cooling. The calculations are based on 0.743 kg CO_2-e per kWh greenhouse emission parameters for power generation [42]. This indicates that a value of 0.743 g of CO_2-e per kWh will be produced during the whole upstream process, which includes the extraction of raw materials, and transportation to the final use of energy by the user. By the calculation, of the cumulative avoided emissions over the next 30 years, this alternative's implementation of DPF materials for thermal insulation could reduce CO_2 emissions by 29,777 kg/CO_2.

4. Discussion

To estimate the thermal loads of the two considered residential buildings, the heating and cooling requirements are calculated based on the comfort temperatures from 20 °C to 26 °C, as described by the NM ISO 7730 standard. The comfort humidity is likewise regulated by this norm at 55% in the winter and 60% in the summer. The results show that the reference case's annual heating and cooling energy requirements in Casablanca are estimated to be 23.7 kWh/m^2 for heating and 24.4 kWh/m^2 for cooling. On the other hand, the yearly energy needs for heating and cooling in the bioclimatic configuration are estimated to be 19.7 kWh/m^2 for heating and 18.1 kWh/m^2 for cooling.

The second configuration is largely adequate to satisfy the regulatory requirements for the Casablanca region, according to a comparison of these values to the Moroccan thermal regulations [7], which imposes a limit of 40 kWh/m^2.year for residential buildings located in this climate zone. As a result, the second configuration (i.e., bioclimatic) reduced the energy needed for cooling by 25% and heating by 18%.

The second configuration's thermal behavior is assessed by comparison with the reference case, as was previously mentioned. The results showed the configuration that is protected by DPF materials' high potential for application. Figures 4 and 5 display the temperature evaluations during the summer and winter seasons, respectively. Additionally, it should be mentioned that the second configuration (the building after DPF insulation) appears to work well in the summer. Indeed, when compared to the reference configuration, the indoor air temperature is reduced by around 2 °C to 5 °C. In contrast, the second configuration is often insufficient during the winter season. That may be because the exterior windows, which are always considered closed, prevent using of solar gains during the day. The temperature of the inside air in buildings will rise when these windows are opened during sunny hours, so comfort during the winter season will be improved by this action.

The comparison of the results found with the results of the researchers is a very interesting step. To this end, we will compare our studies with previous studies. However, there is no study in the literature interested in evaluating the performance of date palm fibers in the building by a simulation modeling approach, to the author's knowledge. So, our comparison will rely on comparison with other sustainable materials.

In Morocco, Dlimi et al. [43] evaluated the thermal performance of an exterior Moroccan building envelope made of two hollow brick walls filled with hemp concrete and separated by a five centimeters air layer. Using TRNSYS software, a dynamic thermal simulation of the study was conducted at the scale of an entire building. According to the results, using hemp insulation on the building's roof and exterior walls lowered the building's yearly heating and cooling needs from 73.92 to 27.19 kWh/m^2.year. Again in Morocco, Ouhaibi et al. [44] compared the thermal and energy performance of two buildings, one built with Poncebloc and the other with conventional materials, for two types of climates: semi-arid Marrakech city and cold Ifrane. According to the findings, using this material as insulation can reduce Marrakech and Ifrane's cooling energy requirements by 66% and 97%, respectively. It also reduced both cities heating requirements by 44% and 42%. Further, in Chenna, Pragati et al. [45] investigated the benefits of urban vegetation by examining how the thermal behavior and heat transmission of a building in a hot, humid climate are affected by its green roofs and walls. Using the simulation software DesignBuilder, the results showed that green roofs and green walls reduce total energy consumption and urban cooling demand by 10.5% and 13%, respectively, and the interior air temperature, radiant heat temperature, and solar gain have all decreased in comparison to conventional buildings without green envelopes by 2.37%, 5.17%, and 73%, respectively.

To conclude this section, it is difficult to judge the performance of one material in relation to another because the performance of each material depends on several parameters, i.e., the climate, the thickness of the material, and the thermomechanical properties of the material.

5. Conclusions

This study deals with the effect of thermal insulation using bio-composite material based on date palm fibers on the dynamic thermal behavior of a house in the Atlantic climate (Casablanca, Morocco). The impact of this passive technique on the thermal load and comfort is analyzed by means of a dynamic simulation carried out using the transient model TRNSYS multizone. Bioclimatic configuration was studied, and its insulating performance was evaluated and then compared with that of a reference configuration. The results obtained showed the high potential applicability of the bioclimatic configuration. It appears that the bioclimatic design works well in the summer because the maximum indoor air temperature is reduced by up to 5 °C in the summer compared to the reference configuration. In addition, about 3 °C increased the indoor air temperature in the winter season. Furthermore, results indicated that the annual cooling and heating demands decreased by 25% and 18%, respectively, when the building roof and external walls were insulated with date palm fiber materials. Moreover, the bioclimatic configuration leads to significant attenuations of GHG emissions.

Additionally, a comparison to the Moroccan Thermal Regulation demonstrates that our findings precisely satisfy these standards and are more effective from thermal, economic, and environmental perspectives.

Finally, the insulating method employed in this research can also be used generally around the world. In fact, the Moroccan city of Casablanca is classified by the Csa classification as having a warm Mediterranean climate, and similar thermal performances can be achieved for the case of several regions with the same warm Mediterranean climate such as South America, Austria, Europe, or California.

6. Recommendations

The current research can be improved by combining it with other passive and semi-passive strategies to create a positive energy building by installing photovoltaic panels. Moreover, studying the thermal performance of these materials in other types of climates would be a worthwhile investigation.

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Nomenclature

Symbols	
A	Frontal surface area [m^2]
C	Correlation parameter for the internal convection heat transfer coefficient [$Wm^{-2}\cdot K^{-n-1}$]
C_i	Thermal capacity of the zone [$J\cdot K^{-1}$]
C_{cover}	Cloudiness factor of the sky
c_p	Specific heat [$J\cdot kg^{-1}\cdot K^{-1}$]
Depth	Depth below the surface [m]
$E_{dif,\,h}$	Diffused radiation on the horizontal [$W\cdot m^{-2}$]
$E_{glob,\,h}$	Total radiation on the horizontal [$W\cdot m^{-2}$]
h_{inside}	Heat transfer coefficient of internal surfaces [$W\ m^{-2}\ K^{-1}$]
$h_{c,outside}$	Heat transfer coefficient of external surfaces [$W\ m^{-2}\ K^{-1}$]
P_i	Heat load of zone i (negative for heating, positive for cooling) [W]
P_0	Atmospheric pressure at the reference height [Pa]
P_{atm}	Atmospheric pressure [Pa]
T_w	Surface temperature of a wall [K]
T_a	Temperature of the ambient air [K]
T_{ext}	Outside temperature [K]
T_{vent}	Air temperature from ventilation equipment [K]
T_{zone}	Temperature of zone [K]
T_i	Temperature of i zone node [K]
T_{sky}	Temperature sky [K]
T_{sat}	Saturation temperature [K]
T_{mean}	Mean surface temperature [K]
t_{now}	Current day of the year [Day]
t_{shift}	Day of the year corresponding to the minimum surface temperature [Day]
U	Thermal transmittance [$W/m^{-2}\ K^{-1}$]
V_{wind}	Wind speed [$m\cdot s^{-1}$]
$\dot{V}$	Volume flow rate [m^3/s]
Greek symbols	
α	Thermal diffusivity [$m^2/s\cdot K$]
ε	Thermal emissivity of a surface
ρ	Density [kg/m^3]

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