The energy efficiency diagnosis of residential buildings in Algeria

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Abstract. Currently, the building sector is considered as one of the most affected by the new measures to improve energy efficiency. As it is clear, worldwide buildings are the largest consumer of the final energy consumption. In Algeria, it has been reported that 33% of the overall energy consumption was attributed to buildings. This stems from the design and construction methods of residential buildings, which do not take into account the region's specific climatic conditions. Many thermal regulations have appeared, and are regularly updated, researches and new techniques are focusing on improving the thermal comfort of buildings while optimizing energy consumption. The study is focused on analyzing the existing residential buildings in Algeria (Mila), in terms of energy efficiency.

1 Introduction

Preserving the environment and reducing energy consumption have become critical global concerns. Buildings, responsible for over 40% of the world's final energy consumption, play a significant role in this challenge [1]. In Algeria, buildings account for 33% of the total energy consumption, with a noticeable increase of 5.3% between 2016 and 2017 [2]. Addressing housing demands and improving low-income families' living conditions have become development priorities in Algeria, leading to the construction of social houses. However, these projects often prioritize cost and speed over considering regional climate conditions, neglecting energy-efficient design principles [3].

This study focuses on analyzing the energy efficiency of existing residential buildings in Mila, Algeria. It aims to identify areas for improvement and propose measures to enhance energy efficiency and occupant comfort. Previous research highlights the critical role of building façade elements in influencing energy consumption and thermal performance [4]. Wall materials, insulation types, and thickness significantly impact heat transfer and thermal comfort [5, 6]. The window to wall ratio and appropriate shading devices are crucial in balancing heat flow and natural light [7, 8].

Moreover, effective ventilation strategies, essential for Indoor Air Quality (IAQ) and CO2 concentration control, can be achieved through thoughtful façade design [9]. By examining various aspects related to energy consumption, thermal comfort, and IAQ, this study seeks to contribute to more sustainable and energy-efficient residential buildings in Mila, Algeria, and beyond.

2 Methodology

The building must integrate with the site's morphology and its existing environment. To achieve energy-efficient buildings, it is necessary to consider a design that allows for energy savings while leveraging the advantages of the construction site. The building's layout will ensure an orientation and arrangement that facilitates capturing solar gains during winter and creating shade during summer. All these solutions, along with a well-designed building insulation, offer significant benefits and enable achieving high energy performance.

The proposed approach in this study aims to explore these parameters in three successive and complementary steps:

Table 1. Three Complementary Steps for Assessing Energy Efficiency in Building Design.

Step	Description
Step 1	Study the effect of glazing orientation, shading percentage, and insulation to demonstrate the importance of bioclimatic design in reducing energy needs.
Step 2	Assess building compliance with Algerien thermal regulations and determine its energy class before and after the parametric study.
Step 3	Highlight the benefits of insulation through an economic study, presenting the additional cost of implementing insulation measures.

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2.1 Case study location

The choice is made on a residential building located in the city of Mila, Algeria. It is a collective residential housing of the LPP type with a surface area of 70.20 m2, and its main facade is oriented to the North. The building comprises two wind-exposed facades, each consisting of exterior walls and windows.

The study is set in Algeria, in a region with a Mediterranean temperate climate according to the Köppen-Geiger classification. This climate is characterized by hot and dry summers and cold winters [10]. The city of Mila has been chosen as a representative city for this climate. It is located in the northeast of Algeria, on the northern edge of the Sahara Desert, at a latitude of 34.8480°N and a longitude of 5.8440°E, and it sits at an altitude of 86 meters.

Based on the climatic data from the city of Mila, obtained from the "Meteonorm 7" weather file over the course of a year, the average temperature in Mila is 15.3°C, and the average precipitation is 501.7mm. The hottest month is July, with an average temperature of 39°C. The climate is very unfavorable between January and February. During midday, the average temperature is around 14°C, and there is an average monthly rainfall of about 87mm [11].

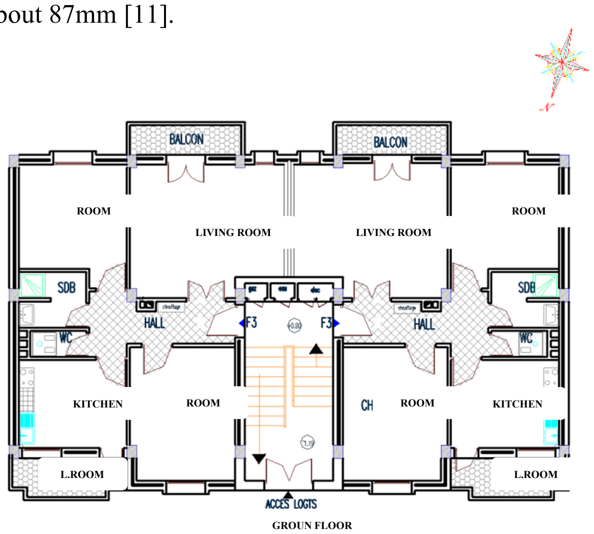

Fig. 1. Plan of the residential building reference.

2.2 Studied Parameters for Energy Consumption Optimization in Buildings

The aim of this section is to determine the best techniques and arrangements to implement during the design and construction phases to optimize energy consumption in a building. The studied parameters are as follows: orientation, shading, isolation.

Table 2. Measures for optimizing energy consumption in a building.

Parameter	Description
Orientation	The study analyzes the impact of glazing orientation on a building's thermal behavior, considering solar gains varying with the sun's trajectory and exposure duration throughout the seasons. The main façade faces North, and thermal losses will be calculated for this orientation. Different orientations will be examined to identify the most energy-efficient direction
Shading	Shading solutions are explored based on sunlight conditions. Solar gains are beneficial in winter but should be minimized in summer to prevent overheating. The optimal shading solutions will differ based on façade orientation and the building's environment. Initially, shading will be omitted, and later, movable shading systems will be proposed to reduce heat gains in summer while allowing sunlight penetration in winter
Insulation	Thermal insulation's role is to resist heat transfer through weak and sensitive areas of the building envelope, including walls, windows, roof, thermal bridges, and floors. The study focuses on applying insulation to vertical and horizontal walls and improving the thermal performance of glazing. The characteristics of different layers will be described, and the coefficient of thermal transmission (U-value) will be identified before and after insulation

Thermal transfers within the building envelope are treated through numerical simulation. Considering that a building wall can involve three different thermal transfers:

- Conduction within the wall,
- Convection between the wall surfaces and the surrounding fluid environments it separates,
- Radiation through infrared rays. The thermal flux exchanged by convection and radiation occurs on both sides of the wall, resulting in an interior flux and an exterior flux. The thermal balance for each surface is expressed as follows:

$$\emptyset_{int} = \emptyset_{cond} = \emptyset_{ext} \quad (1)$$

The total dissipated flux is calculated in a continuous regime, independent of the heating system, and includes the following components:

- The flux through the walls via transmission,
- The flux through air renewal,
- The flux through linear transmission between the walls.

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$$\emptyset_T = \emptyset_s + \emptyset_l + \emptyset_{vent} \quad (2)$$

2.3 Numerical simulation

The thermal study is conducted using a numerical simulation software called "CLIP." The simulation principle involves dividing the building into basic elements: walls, floors, and glazing. The software allows the determination of the building's energy consumption in each case, comparing it with the Algerien thermal regulations, and providing its consumption class. The calculations are performed by determining the annual energy requirements for heating during the winter period, assuming a base indoor temperature of 18°C, and the annual energy requirements for cooling during the summer period, assuming a base indoor temperature of 23°C [12].

3 Results and discussion

3.1 Orientation

The studied building has a main North-facing facade. To highlight the effect of glazing orientation, the thermal needs for both winter and summer were calculated and compared to South, West, and East orientations. The analysis considered only the facade under study, with a constant surface for the other external walls, and used 6mm single glazing. Figure 3 displays the winter energy needs related to thermal comfort for the four directions. South direction shows the most energy-efficient performance with the lowest needs (40 kWh/m2), while North direction exhibits significantly higher needs, gradually increasing from 37 kWh/m2 to 50 kWh/m2. This result is explained by the better solar exposure of the South-facing wall, naturally illuminated during the most favorable hours of the day, whereas the North-facing wall receives minimal useful solar gains in the cold season, leading to discomfort, humidity, and mold issues.

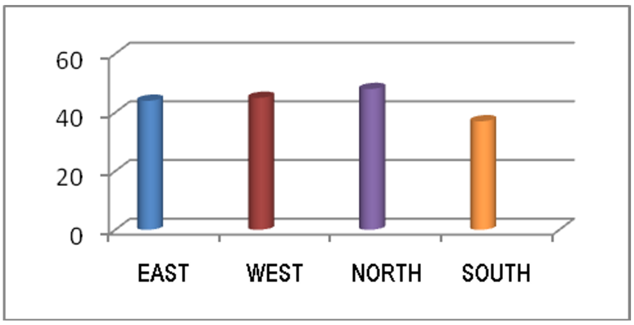

Fig. 1. Heating energy requirement.

The shift from a North orientation to a South orientation results in a gain of approximately 18% in winter. During the summer, the North direction remains shielded from direct sunlight. On the other hand, solar gains for the South direction are limited as the sun's trajectory is above the building. The use of solar shading devices for windows can significantly reduce solar radiation. While energy needs in the hot season have been greatly reduced for the North direction, the South direction remains the most effective. Figure 2 illustrates the annual energy needs for the different orientations.

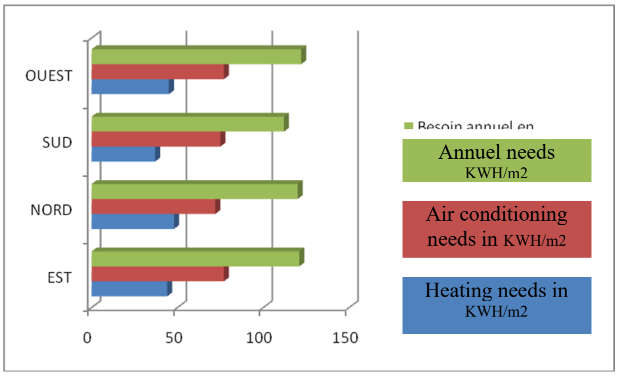

Fig. 2. Annual energy needs for different orientations.

After the South direction, the East becomes the second most favorable orientation, with an annual energy demand of 118.75 KWh/m2. The primary challenge for both the East and West orientations lies in the direct entry of solar rays through openings, which proves difficult to control with solar shading. In the summer, solar rays from the West coincide with the hottest part of the day, impacting occupants' thermal comfort.

3.2 Shading

Considering a South-facing main facade, the objective remains to enhance the building's thermal performance. Now, the study takes into account the actual geometry of the building. Solar rays act as a source of heat gain and illumination in winter and cause overheating in summer, necessitating their reduction for improved comfort. Shade creation is proposed, and various shading percentages (ranging from 10% to 50%) were analyzed. Figure 3 illustrates the variation of thermal needs in summer concerning the shading percentage. The results show that higher shading percentages lead to reduced energy requirements during summer.

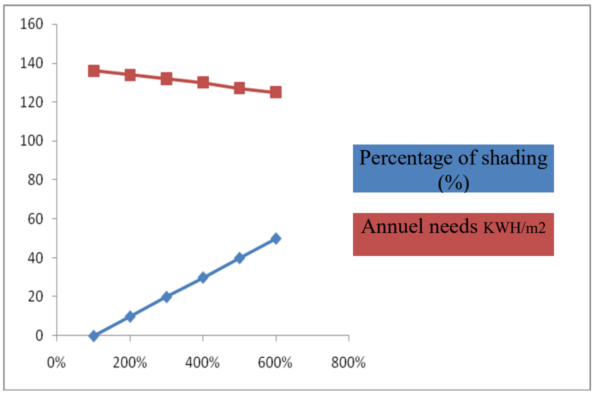

Fig. 3. Heating Evolution of Energy Needs in Summer Based on the Percentage of Shading.

3.3 Insulation

The building's location and thermal envelope have a significant impact on the amount of energy consumed. The building under study is exposed to the external environment on all sides, leading to increased heat transfer to the outside. Insulation is one of the most effective measures to reduce thermal losses, as evidenced by the results in Table 3. The annual energy requirement was significantly reduced from 125 KWh/m2 before insulation to 57 KWh/m2, representing a 46% gain. The economic benefits depend on the type and thickness of the insulation used. For exterior walls, a 4 cm thickness is justified by the air gap, while for the roof, increased thickness improves insulation, but cost and ease of execution should not be overlooked.

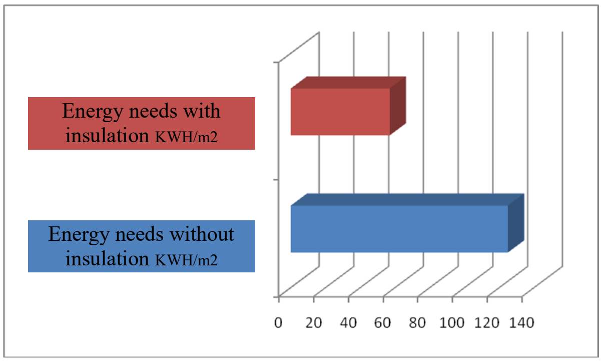

Fig. 4. Energy needs before and after isolation.

The above has demonstrated the importance of considering all parameters to optimize consumption and improve comfort. It is evident that relying on a single parameter is not sufficient to ensure optimal comfort. Taking into account all parameters enables achieving a significant gain that provides multiple advantages.

4 Conclusion

In conclusion, the study emphasizes the significance of energy-efficient measures for residential buildings in the Mila region of Algeria. The findings underscore the importance of parameters like orientation, shading, and insulation in reducing energy consumption and promoting environmental integration. Adopting a bioclimatic approach and optimizing the building envelope can play a pivotal role in curbing energy needs, lowering CO2 emissions, and enhancing overall energy efficiency. The installation of insulation stands out as a practical solution, offering both financial savings and improved building durability. By implementing these strategies, the region can make substantial progress towards achieving sustainable development goals and ensuring a greener and more energy-conscious future.In contrast, in the study conducted in a Saharan city, the result presents a comprehensive analysis of a selected residential building in Algeria, revealing non-compliance with energy design standards and weaknesses in energy consumption, thermal and visual comfort, and indoor air quality. The analysis suggests a need for design adjustments, including optimizing external wall materials for improved thermal comfort and reduced energy usage. Window configuration and orientation are highlighted as pivotal for visual comfort and solar irradiation mitigation. The integration of mechanical and natural ventilation is also underscored to enhance indoor air quality. This analysis underscores that energy efficiency considerations should be integrated early in the design process, focusing on the hottest period when cooling consumption is at its peak.While both results share the objective of enhancing energy efficiency, your provided result centers on the broader benefits of energy-efficient measures, insulation, and sustainability goals, while the second result delves into specific weaknesses of an analyzed building and outlines targeted design strategies to rectify its shortcomings.

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