J Ther Eng, Vol. 12, No. 2, pp. 767−783, March, 2026

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.14744/thermal.0001118

Research Article

Energy and financial efficiency of a single family house in Algeria, the best way to get rid of state subsidies

Rabea KAOULAL[1], Sifia BELGHERRAS[2], Sidi Mohammed El Amine BEKKOUCHE[3]

[1]*Science of Matter Department, FFaculty of Material Sciences, Mathematics and Computer Science, University of Adrar, Adrar, Algeria*
[2]*Faculty of Science and Technology, University of Ghardaïa, BP 455 Airport Road, Noumerate, Ghardaïa, Algeria*
[3]*Applied Research Unit on Renewable Energies (URAER), Renewable Energy Development Center (CDER), Ghardaia, Algeria*

ARTICLE INFO

Article history
Received: 13 January 2025
Revised: 11 March 2025
Accepted: 06 April 2025

Keywords:
Building's Energy Balance, Thermal Rehabilitation, Energy Efficiency, Subsidies, Return on Investment

ABSTRACT

Financial aid and subsidies for electricity are intended to mitigate the impact of energy bills on low-income households. Unfortunately, these subsidies can represent a significant financial burden for governments. By eliminating them, states can reduce their budget deficit and reallocate those funds to other priorities, such as education or health. Several methods and alternative solutions to avoid or reduce dependence on electricity subsidies can be considered, but they will need to be adapted to the specific context of each country or region. Promoting energy efficiency will help consumers to reduce their electricity consumption and offset price rises. The integration and investment in renewable energy are essential to diversify energy sources and reduce dependence on fossil fuels. These two actions can effectively reduce the need and dependence on subsidies by decreasing demand. Moreover, by implementing more rational aid programs instead of subsidizing fossil electricity for low-income households, it will be highly possible to encourage states to stabilize their budgets acceptably by reallocating funds to other priorities. This study aims to evaluate the energy and economic performance of the Algerian buildings. This paper quantitatively analyzes the financial and energy efficiency of buildings and, rehabilitation projects of single-family houses in all of Algeria's climatic regions. An assessment of the building's overall energy balance was the basis of the investigation method. According to the obtained results, the current state subsidy system will not have to be fully maintained. Eliminating or reducing electricity subsidies is a complex process that requires a thoughtful and gradual approach. It must be carried out gradually and accompanied by protective measures for vulnerable households. To avoid negative impacts on the purchasing power and well-being of citizens, these measures must be based, firstly, on specific and limited investments and financial aid according to climatic regions, unlike what they were at the beginning (unlimited); secondly, on the judicious integration of renewable energies; and thirdly, on strengthening energy efficiency. From a financial point of view, subsidies are significantly lower for lower cooling energy needs. By adopting rehabilitation measures, unsubsidized energy bills are lower than those corresponding to a conventional home without thermal rehabilitation and with subsidized bills. Subsidizing the thermal rehabilitation procedure, or subsidizing thermal rehabilitation, a suitable solar water heater and, a stand-alone, optimized

***Corresponding author.**
*E-mail address: kaoulal.r@gmail.com

This paper was recommended for publication in revised form by Editorin-Chief Ahmet Selim Dalkılıç

Published by Yıldız Technical University Press, İstanbul, Turkey

and well-sized photovoltaic system at the same time, can be a good alternative for effectively reducing the need for and dependence on subsidies by reducing demand or getting rid of these subsidies altogether. The most suitable regions for financial assistance, ranked according to merit, are M'sila, Naâma, Biskra, Bechar and, lastly, the Drabla climatic region.

Cite this article as: Kaoulal R, Belgherras S, Bekkouche SMAB. Energy and financial efficiency of a single family house in Algeria, the best way to get rid of state subsidies. J Ther Eng 2026;12(2):767−783.

INTRODUCTION

Energy efficiency in building construction is of paramount importance, especially in Algeria, a country with varied climates. This study embarks on a comprehensive exploration of energy efficiency in these different climatic zones. This action seems to us very obligatory, as state subsidies indirectly risk depleting our natural resources. Electricity is mainly generated from the main fossil fuels, which account for almost 99.6% (Oil: 35%, natural gas: 64%, coal: environ 0.6%) of domestic primary energy consumption. In the same context, the electricity bills allocated to Algerian citizens do not reflect the reality of electricity production and distribution costs. The program focuses on subsidizing consumers' electricity bills. State subsidies for electricity bills in the Algerian region amounted to 18.9 billion Dinars in 2020. Consumers will subsequently be encouraged to use electricity more efficiently and rationally. Moreover, in some countries, such as Algeria, subsidies can sometimes favor fossil fuels and non-sustainable energy sources. At the heart of this issue, the Minister of Energy pointed out that the average price per kWh of electricity in Algeria, for high, medium and low voltage, is low compared to other countries around the world. Subsidies also distort resource allocation, by encouraging excessive energy consumption, artificially favoring capital-intensive industries, reducing incentives for investment in renewable energies, and accelerating the depletion of natural resources (our situation). The main aim of this study is therefore to propose an efficient process and passive architectural concepts that can put an end to this government financial aid without having negative economic and social impacts. This document includes ideas for reforming energy subsidies. The application field of electricity-related subsidies primarily concerns the building sector, as this sector represents a significant portion of energy consumption in Algeria and several countries around the world. The results and conclusions reached appeal to a broader audience, including practitioners and decision-makers. The training of professionals to raise awareness of new practices and technologies, as well as collaborations with companies in the construction and energy sectors, are of crucial importance for implementing these results. The indication of the terms of the grants and the use of the results to raise awareness among the general public and policymakers about the importance of energy efficiency in buildings is very essential. Cooperation and joint work with state agencies to integrate research findings into building regulations and standards are more than necessary. The results can also be used to initiate new research projects or the development of innovative technologies in the building energy field. Following this observation, it is possible to transform the results of this research into concrete actions that improve the energy efficiency of buildings and contribute to environmental sustainability. The application of grants will primarily be dedicated to renovation work aimed at improving the energy efficiency of housing, such as thermal insulation, window replacement, or the installation of more efficient heating/cooling systems. They can also be used to finance social housing construction projects, thereby making energy more accessible, encouraging sustainable practices, and improving the living conditions of citizens. In summary, subsidies play a crucial role in the energy transition by helping households reduce their energy consumption, lower their electricity bills, and contribute to the fight against climate change.

The energy and financial efficiency of buildings is a constantly evolving field, but several concepts and practices are already well established. Many countries have established building standards that require minimum energy performance, such as the RT 2012 standard in France or the energy code in Canada. Certifications such as LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method), and HQE (High Environmental Quality) promote sustainable construction and energy efficiency. Energy technologies such as thermal insulation, renewable energy sources that contribute to the energy autonomy of buildings, energy management systems based on monitoring and optimization sensors, software for real-time data analysis, energy audits that identify opportunities for improving energy efficiency, and bioclimatic design that takes into account the building's orientation, the use of natural light, and natural ventilation to reduce energy needs, have seen significant developments over the past decade. Despite all these advancements, this field is still evolving, with an increasing focus on innovative financing models and financial incentives to encourage energy efficiency projects, sustainability, and resilience in the face of environmental challenges, particularly under harsh, unfavorable, or degrading climate regimes. In the field of energy and financial efficiency of buildings, several research gaps can be identified and need to be filled. These include:

- Longitudinal data and case studies: there is a significant need for long-term data on the energy performance of buildings after their construction and occupancy to understand the factors that influence energy efficiency over the long term.
- Some new technologies deserve to be explored more deeply, such as energy management systems, intelligent sensors, and innovative materials.
- Research on the impact of occupant behavior on energy consumption is still limited.
- The effective integration of renewable energies into buildings, particularly regarding energy storage and demand management.
- Regulations on energy efficiency in buildings are still insufficient and are not always well understood. Further research can help identify best practices and the most effective policies.
- Adapting buildings to future climatic conditions.
- The need for effective and innovative financial models to support investments in energy efficiency and research into financing mechanisms for a smooth energy transition, to overcome financial barriers, and to improve the living conditions of citizens.

Reducing electricity subsidies is, therefore, a complex issue that requires a thoughtful approach. This reduction is necessary for several reasons:

- First, subsidies can place a heavy burden on public budgets, limiting the resources available for other essential services such as health or education.
- Secondly, to encourage consumers to use electricity more efficiently and adopt more responsible consumption behaviors.
- Thirdly, subsidies can sometimes favor fossil fuels or outdated technologies.
- Fourthly, the reduction or elimination of subsidies leads to a reallocation of resources towards more targeted programs for low-income households.

The reduction of electricity-related subsidies involves evaluating existing subsidies, i.e. analyzing current subsidies to understand their economic, social, and environmental impact. The second step is to identify those that are ineffective or do not meet their objectives. It is necessary to establish scientific work, and transparent communication can help gain the support of citizens from different categories and inform them about the reasons for the reduction or elimination of subsidies and the expected benefits. But at the same time, it is necessary to implement compensatory measures to mitigate the impact on vulnerable households, through targeted assistance or other support programs for those most affected by the rise in electricity prices.

As part of this objective, recent work by Manić et al. [1], has made it possible to estimate the energy performance of existing buildings, labeling and evaluating energy-saving measures and energy strategies to be implemented in the Republic of Serbia. In fact, particular attention has been drawn to the energy efficiency of existing buildings which, according to the work carried out, average energy consumption in Serbia is over 150 kWh m^{-2} per year, compared with around 50 kW m^{-2} per year in developed European countries [2]. On the other hand, the Savski Venac municipality's local development strategy was based on appropriate energy efficiency measures aligned with its energy policy [3]. However, the most effective energy-saving measures for energy-efficient buildings are improving the performance of the air-conditioning system and the thermal properties of walls and windows in Guangdong province, China. The sum of the energy-saving rates for the cooling system, walls and windows is around 56% [4]. Moreover, to meet all these commitments, at least one of the passive or active concepts needs to be integrated. It's a well-known fact that reducing a home's energy requirements systematically leads to lower energy bills. Especially as the thermal insulation is the most popular passive technique. But before undertaking any thermal insulation work, there are a number of prerequisites that must be met to fully understand the issues involved. In response to this request, targeted studies [5-7] of the factors affecting the optimum insulation thickness and its pay-back period, including the building's heating and cooling energy requirements, lifetime, the costs of insulation materials and installation, the costs of energy sources for heating and cooling, the efficiency of heating and cooling systems, and solar radiation, were fundamentally addressed.

As insulation helps to reduce energy consumption, it can also reduce carbon emissions, as fewer fossil fuels are burned [8, 9]. The financial profitability of thermal insulation has been the subject of several investigations. A comprehensive analysis by Canbolat [10] was carried out to determine the impact of the heating source type (natural gas, electricity, fuel oil), insulation materials (expanded polystyrene, extruded polystyrene, mineral wool, polyurethane foam), the climate zone (Adana, Çanakkale, Konya, and lastly Van) and the building use (summer house, winter house or all-season house) on the optimum insulation thickness. Efficiency measures with the fastest return on investment, shortest implementation time and lower complexity have been confirmed by the technical-economic analyses [11]. Efficient hospital lighting, in this case, is the most effective way of reducing budget expenditure. However, the greatest potential for energy savings comes from space heating through thermal insulation of the roof and external walls, efficient windows and the introduction of an efficient diesel heating system. Implementing and improving the building management system is also an important measure [11]. Adamczy et al. [12] have proposed a methodology for assessing the economic and ecological benefits resulting from changes in user profile and thermal insulation performance. Financial analyses were carried out taking into account the year of construction of the building, the type of heat sources and thermal insulation, user profiles in the room and technical and social requirements. The social dimension of the approach was significant, as the aim was to reduce expenditure on thermal upgrading of buildings, particularly in areas of energy and economic poverty. Changing temperature habits in the home can have a significant impact on saving energy resources. Another study focusing on Europe [13] showed that investments in thermal insulation in the building sector can have a significant impact on improving the energy efficiency of buildings and reducing end-energy use in this sector. The use of important indicators, such as: net present value, profitability indicator, ecological and financial payback period, showed that payback periods ranged from 0 to 6 years. On the other hand, in 2017, the importance of investing in thermal insulation was examined by Dylewski and Adamczyk [13], taking into account the state of the building before thermal insulation, the type of building materials, the heat source to be used, the type of thermal insulation and the climate zone in which the building is located. The results indicate that the investment is beneficial regardless of the regions examined in this article. They are most promising for the colder climate, a building that had the worst thermal performance before thermal insulation, the most expensive type of heat source (i.e. the highest costs to obtain 1 kWh of thermal energy) and the least expensive material used for thermal insulation [14].

The first observation to be drawn from a literature review in this field, which has a direct socio-economic impact on homeowners, is the inadequacy of certain well-targeted and quantified technical results, particularly those concerning very hot regions in Algeria, often characterized by particular extreme climatic conditions. A new approach will be proposed to address the current profitability issue in these similar regions. For this purpose, the arguments to be provided help to communicate new ideas that advance research. The theoretical framework is an updated art state from the previous research. The formulation of our problem will involve the development of some key concepts and their definitions. We can justify the investigation, suggest a new angle on it, expand already conducted research, and most importantly, bring a new proposal to the debate. In line with all these steps, the first objective will therefore be to conclude exhaustive financial charges of the insulation procedure with a personalized user manual, the justifications for the choice and their return on investment. Expanded polystyrene has been favored over thermal insulation materials due to its ease of handling on construction sites, its resistance to moisture and water (which makes it an ideal choice for applications in humid environments, such as basements or foundations), its durability (so it is stable over time and does not deform easily), its ease of implementation, its competitive cost (which makes it an economical option for many projects), non-toxicity, and it also provides some acoustic insulation.

Furthermore, energy subsidies are one of the instruments used by governments to achieve political, social and environmental objectives. In 2022, the latest estimates from the International Energy Agency indicate that the global subsidies to support fossil fuel consumption had reached over $1000 billion. Worldwide subsidies for the consumption of natural gas or electricity (from fossil fuels) have more than doubled, while those for oil have risen by 85% [15]. These subsidies are particularly intended to the developing countries to correct the poverty effects and promote economic and social development by providing access to energy at affordable prices. But, the negative impact of this consumption on carbon emissions has been widely criticized. Subsidies have also criticized for distorting relative financial charges and the supply-demand balance; they lead to a significant economic surplus loss, which must be offset by the social benefit sought by each subsidy. Due to their conflict with climate objectives, they are currently being criticized, making their elimination a key objective. The most subsidies are typically given to oil-producing countries. This has led the International Monetary Fund (IMF) and the World Bank, even before 2022, to introduce a climate policy agenda. They considered that fossil fuel subsidies and criticisms are mainly due to their productive (disincentives for industrial and commercial energy companies, leading to deficits and under-investment), allocative (fuel over-consumption) and environmental inefficiency. It has been noted that these subsidies are not well-directed. Political legitimate objectives cannot prevent the elimination of subsidies [16]. To deal with this complicated issue, and to avoid binding commitments by countries that would be unrealistic, an effective and profitable method from an energy, economic and financial point of view will be proposed. The issue of financial subsidies for electricity from the conventional grid is therefore an aspect that is very poorly documented and often partial. We have not found studies conducive to comparison; it has already been noted that even in the presence of a few rare works that partially fit into this same context, few studies if any have gone so far as to propose alternatives that would reduce or eliminate the current forms of subsidies. With this in mind, the proposed solutions can be considered innovative and may be extended to other similar regions across the globe in the near future.

SUMMARY OF THE METHOD: BUILDING'S OVERALL ENERGY BALANCE

The energy balance provides an overall assessment, control and diagnosis, which will subsequently, determine the work to be undertaken to improve the energy efficiency of any building. It should take into account the specific nature of the building (used materials, level of thermal insulation, walls, floors, openings, etc.), ventilation systems, heating and domestic water production, household appliances and lighting systems, and integrated passive and active energy concepts. The following equations [17-23] serve as the basis for energy requirement calculation for heating (1) and cooling (2), respectively.

$$Con_{Tot} = Con_{Env} - \left(Hg_{Occupants} + Hg_{Lighting/Other} + Hg_{Solar}\right) + Con_{DHW} + Con_{Load} \quad (1)$$

$$Con_{Tot} = Con_{Env} + \left(Hg_{Occupants} + Hg_{Lighting/Other} + Hg_{Solar}\right) + Con_{DHW} + Con_{Load} \quad (2)$$

The sum $\mathrm{Hg_{Occupants}} + \mathrm{Hg_{Lighting/Other}} + \mathrm{Hg_{Solar}}$ represents free solar gains.

$\mathrm{Con_{Env}}$ is, by definition, the energy consumption due to the building envelope (Wh) [17-21]

$$Con_{Env} = 24\ Dj\ Hlos_{Env} \quad (3)$$

$$Hlos_{Env} = Hlos_{Walls} + Hlos_{Roof} + Hlos_{Low-floor} + Hlos_{Doors} + Hlos_{Windows/Opnings} + Hlos_{Thermal\ bridges} + Hlos_{Ventilation} \quad (4)$$

$Hlos_{Ventilation}$: the amount of heat loss from the ventilation system and each element (W/K), calculated using the detailed methods given in references [17-21].

Con_{DHW}: the average energy requirement for daily water heating (Wh). This is a major energy item counted by the daily volume of the water to be heated per person (liters/day/person), the useful temperature (°C) of the hot water and the temperature difference (°C) with that of use [22, 23].

$$Con_{DHW} = \rho\ 1.1628\ Vol_{DHW}\,(T_{DHW} - T_{CW}) \quad (5)$$

Where ρ is the water density, measured in kg/liter in this case. It ranges from 999.841 kg/m^3 at 0 °C to 958.40 kg/m^3 at 100 °C and is generally maintained at 0.99 kg/liter until around 55 °C [24].

Vol_{DHW} signifies the amount of domestic hot water required for the user's use (liters).

T_{DHW} and T_{CW} are respectively the temperature of the domestic hot water and the cold water at the inlet to the heating system (°C or K)

For this undertaken work, Vol_{DHW} = 50 liters per occupant and T_{DHW} = 50 °C will be retained.

The internal heat gains (Wh) are evaluated according to the building purpose which is mainly due to the body heat and occupant's activity $Hg_{Occupants}$, the lighting, electrical appliances, devices and significant usage of equipment's, cooking, etc. $Hg_{Lighting\ /\ Other}$ [17-21].

$$Hg_{Occupants} = Nb_{Residents}\ \varphi_{Occupants}\ Nb_{Days}\ Dur_{Residents} \quad (6)$$

$Nb_{Residents}$: number of residents occupying the building

$\varphi_{Occupants}$: heat flux released by the human body per occupant (W)

Nb_{Days} : number of days to be heated / cooling

$Dur_{Residents}$: the mean duration of the resident presence per occupant (hours per day)

$Hg_{Lighting\ /\ Other}$ is the heat flux released by lighting, electrical appliances, devices and significant usage of equipment, cooking, etc (W) [17-21]

$$Hg_{Lighting/Other} = Nb_{Days}\ \ Dur_{In\ operation}\ \ \varphi_{Lighting/Other} \quad (7)$$

$Dur_{In\ operation}$: the total run time of the lighting system and all equipment to be powered (hours per day)

The incoming passive solar gain is also taken into account by the orientations of the glass facade walls. It is calculated as follows [17-21]:

$$Hg_{Solar} = \sum_j I_j \sum_n A_n(j) = \sum_j I_j \sum_n Aop_n(j)\ Fs_n(j)\ S_n(j) \quad (8)$$

Where n represents the number of the transparent opening fronts. I_j is defined as the daily solar irradiance incident on a unit surface of orientation j *(Wh/m^2)*. $A_n(j)$ is an equivalent receiving surface (sum of surfaces of transparent opening fronts) of an orientation j, used to determine the building's capacity to capture solar gain. $Aop_n\ (j)$ is the opening area (m^2) corresponding to the window n of the orientation j. $Fs_n\ (j)$ represents the shading correction factor according to the orientation j. S is the solar factor for windows n of the orientation j.

The energy consumption for electrical loads (any component of a circuit that consumes electrical power) in buildings is estimated in Wh according to the following equation:

$$Con_{Loads} = Nb_{Days}\ \ P_{Elec}\ \ Dur_{In\ operation} \quad (9)$$

P_{Elec} is the electrical power of equipment (W).

Study Cases

Building Model

The case studied is a single-story house with an area of 126.69 m^2 and a volume of 380.07 m^3 as shown in Figure 1. It consists of a living area, kitchen, bathroom/WC, kids' bedroom, parents' room with cupboards, and stairway. Windows maximize the entry of natural light, thereby reducing the need for artificial lighting during the day. It is possible to benefit from fresh air through windows or a well-designed and maintained mechanical ventilation system.

The thermophysical properties of building materials of the built environment and the type of occupancy are given in Table 1 below.

Climatic Data and Brief Description of the Country's Regions

In this investigation, energy efficiency was assessed in any climatic zone. Algeria is the largest country bordering both Africa and the Mediterranean due to its vast surface and diverse range of climate zones, as depicted in the Köppen-Geiger globe map. The selection of eligible locations has been based on seven climatic zones (according to the

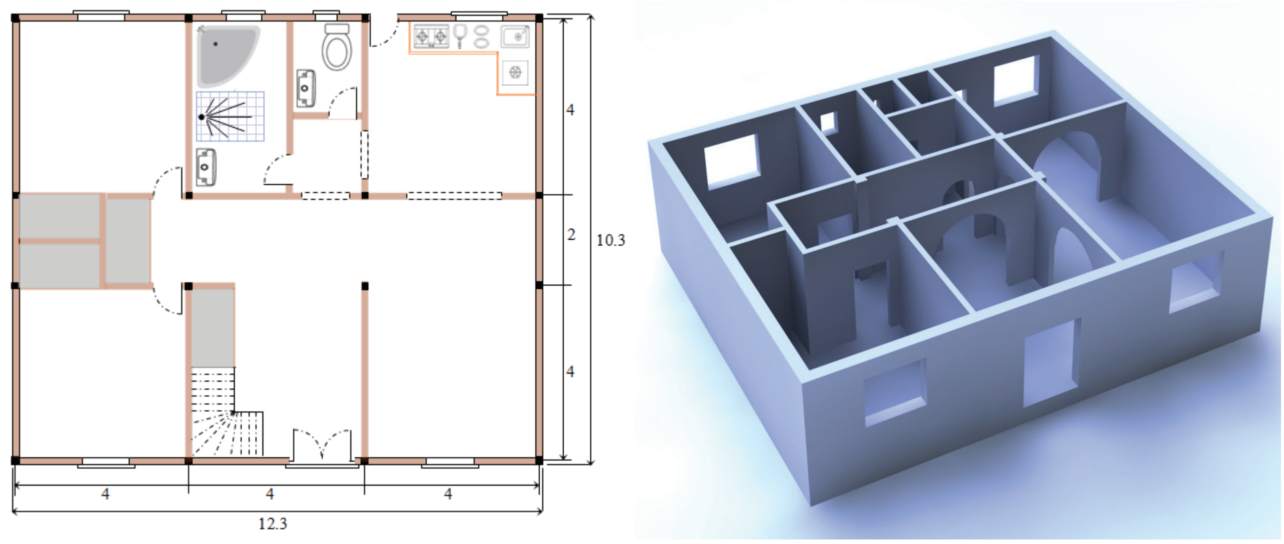

Figure 1. Approximate illustrative design of the parts in the building space.

Table 1. Thermal and occupancy properties of the house

		1st case	2nd case : with thermal rehabilitation (external thermal insulation + passive solar gain)
	Walls of the building envelope	1.71	0.31
	Roof	3.06	0.51
U	Soil	1.14	0.31
W/(m² °C)	Thermal bridges	1.07	0 : eliminated
	Windows on a wood frame	Single-glazing: 5.00	Double-glazing : 2.55
	Opaque door made of	Metal : 5.80	Wood: 3.50
Glazed surfaces		95% of the total window surfaces	
Hygiene flow (infiltration and permeability)		60.5 m^3/h	
Air exchange loss coefficient (natural ventilation)		40 m^3/h	
Number of occupants in the building		5 occupants	
Average hot water requirement per occupant		60 liters per day at 50 °C	
Average occupancy		15 hours per day per occupant	
Comfort temperature		Between 21 °C and 26 °C	

Table 2. Climate classification and geographical coordinates of the study regions

Climatic zones	Climate classification	Latitude	Altitude	Longitude
Setif	Mediterranean climate with a hot summer	36° 09′ 00″ North	1100 m	5° 26′ 00″ East
M'sila	Semi-arid cold climate	35° 33′ 0″ North	968 m	6° 10′ 12″ East
Bechar	Dry and hot desert climate	31° 37′ 0″ North	773 m	-2° 13′ 0″ West
Biskra	Dry and hot desert climate	34° 51′ 01″ North	120 m	5° 43′ 40″ East
Naâma	Dry and cold desert climate	33° 15′ 44″ North	891 m	0° 18′ 52″ West
Drabla	Hot temperate climate	35° 0′ 0″ North	1380 m	7° 0′ 0″ East
Mohamadia	Semi-arid cold climate	35° 35′ 25″ North	30 m	0° 04′ 12″ East

Köppen-Geiger classification) that are dispersed throughout Algeria to account for all potential scenarios. Figure 2 and Table 2 below display the chosen towns' geographic coordinates.

The climate of Setif is semi-arid and transitional Mediterranean with some continental characteristics. There are occasional cold snaps and snowfalls (on average 12 days a year) in the city during the somewhat cold winter. Summertime at this altitude is scorching, even hotter than it is along the shore. At times, the temperature might get to 40 °C. The Köppen-Geiger climate map, which is displayed

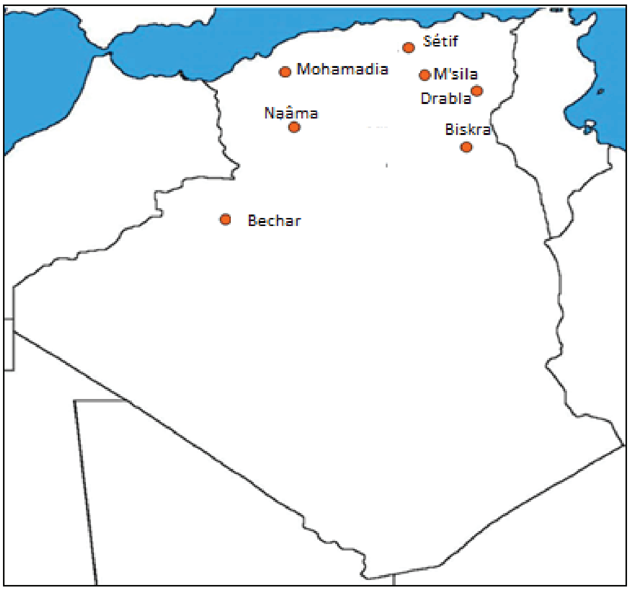

Figure 2. Geographical location of the climatic sites.

by the National Institutes of Health's US National Library of Medicine, indicates that Setif has a "Csa" type climate, which is characterized by hot summers and temperate steppe. However, M'Sila has a BWh desert climate, which is hot and dry. Throughout the year, there is little rainfall in M'Sila. Annual rainfall is 249 mm according to meteorological records. The average temperature in M'Sila is 18.6 °C. Likewise, Biskra and Bechar are classified similarly since their yearly average temperature consistently rises above 18 °C. The town of Biskra is located in northeast Algeria, on the edge of the Sahara Desert. The climate is subtropical desert, with hot, bright summers and mild winters that can get chilly at night. The average annual temperature is 21.8 °C. Rainfall in a year is 141 mm on average. Bechar is located in western Algeria at a height of 780 meters and a latitude of nearly 32 degrees north. Its climate is subtropical desert, with hot, sunny summers and mild winters (during which it can be cold at night). The mean annual temperature is around 20.2 °C. Moreover, the Wilaya of Naâma lies at an altitude of over 1000 meters on the high plateaux and is crisscrossed by the Saharan Atlas chain. The climate is continental, with very hot, arid and generally clear summers and chilly, dry, windy and partly cloudy winters. Monthly rainfall varies seasonally to a modest extent. Over the year, the average annual temperature fluctuates between 2 °C and 36 °C; it rarely falls below -1 °C or climbs beyond 39 °C. On the other hand, Drabla's climate is warm and temperate. The yearly mean temperature and precipitation are 11.5 °C and 623 mm, respectively. Finally, Mohamadia has a "steppe" climate. There is hardly much rainfall during the year. The average annual temperature is 18.4 °C, and there are roughly 351 millimeters of precipitation [25-27].

In Figure 3, average monthly temperatures are displayed.

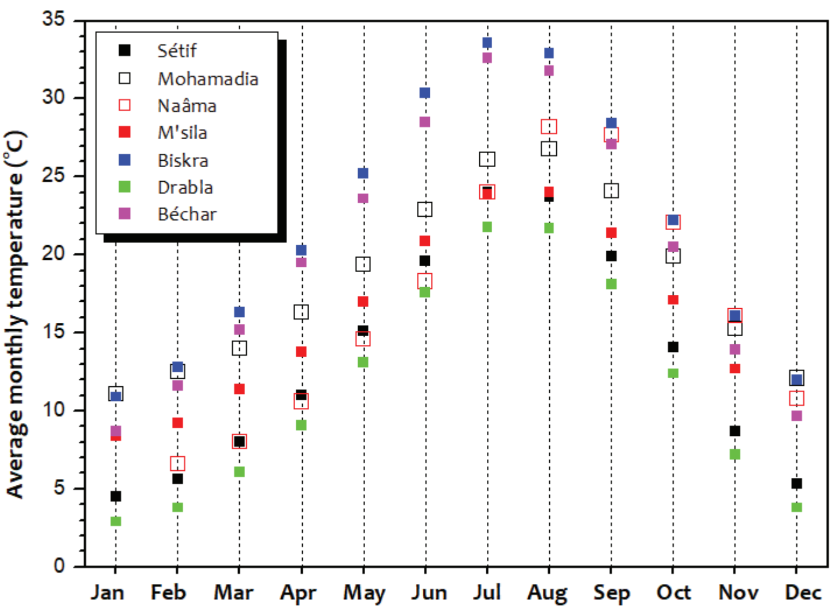

Figure 3. Average monthly temperatures for several climatic regions.

RESULTS, ANALYSIS AND DISCUSSION

As mentioned in Table 1, the setpoint temperature that determines the desired thermal level in this case was set at a range of 21 °C - 26 °C. This choice was principally motivated for energy-saving reasons. According to the Agency for the Environment and Energy Management "ADEME", by lowering the heating setpoint by 1 °C, 7% of the heat energy can be saved. By increasing the temperature from 22 °C to 26 °C, energy consumption can be halved [28]. The comfort temperature during overheating was tolerated at 26 °C. To not compromise, preserve the comfort and match the body's metabolic rate, which varies depending on muscular activity, the environment and body size, the user-set heating temperature has been kept at 21 °C.

Diagnosis of Thermal Comfort Periods

This study's initial phase involves comparing climate regimes by figuring out which days needed heating and cooling. Days with adequate ventilation that allow outside air to enter the house at a comfortable temperature are associated with comfortable levels of comfort. Figure 4 displays an early comparison of the study's climatic circumstances, which can express the level of perceived comfort as a function of the amount of energy exchanged between the user and his surroundings.

Csa' type climates are found in many parts of the world, mainly around the Mediterranean Sea, in the south of Australia, in the southwest of South Africa, in certain parts of Central Asia, in the northern parts of Iran and Iraq, and so on. In hot desert climates of the BWh type, such as M'Sila, Oaxaca in Mexico and the Saudi Arabian desert, the heating period can be as high as 76.79%. The period is still long for BWk climates, such as Naâma, which is equivalent to 69.54% of the year, and the Gobi Desert in Mongolia. As it moves further south, the duration of the heating period decreases, approaching 50% of the year. It is 49.77% and 53.25% of the year, respectively for the regions of Biskra and Bechar. In the same context, the overall number of comfortable days during the year is low, ranging from 11.98% to 16.55%, which justifies the short off-season periods. The Mohammadia region, on the other hand, is slightly more interesting, with an estimate of 24.63% of the year.

Assesment of Energy Needs

Figure 5 shows detailed results of the monthly energy demand according to the indicated climate regime, associating them with the share of heating and cooling demand (a and b). A comparison of the annual energy demand was also made between the two houses after thermal rehabilitation according to the second case in Table 1 (c). An energy classification of the two buildings according to the climatic region was carried out, assigning the appropriate energy label in each case (c).

The first observation has been referred to the record levels of energy needs in the climatic zones of Drabla and its surrounding areas. The unrenovated single-family house proposed in this study is, as a result, an energy-intensive building (type "G" label) in Setif's, Naama's and Drabla's climates. The Mohamadia site will provide much more favorable climatic conditions for this type of building. Energy consumption will be minimal and more advantageous compared to other sites (type "E" label) without thermal rehabilitation. Buildings with similar climatic conditions to those in M'sila, Bechar and Biskra can be joined by buildings with an "F" energy label. In this awkward situation, the thermal and energetic rehabilitation of dwellings has to face up to a triple challenge:

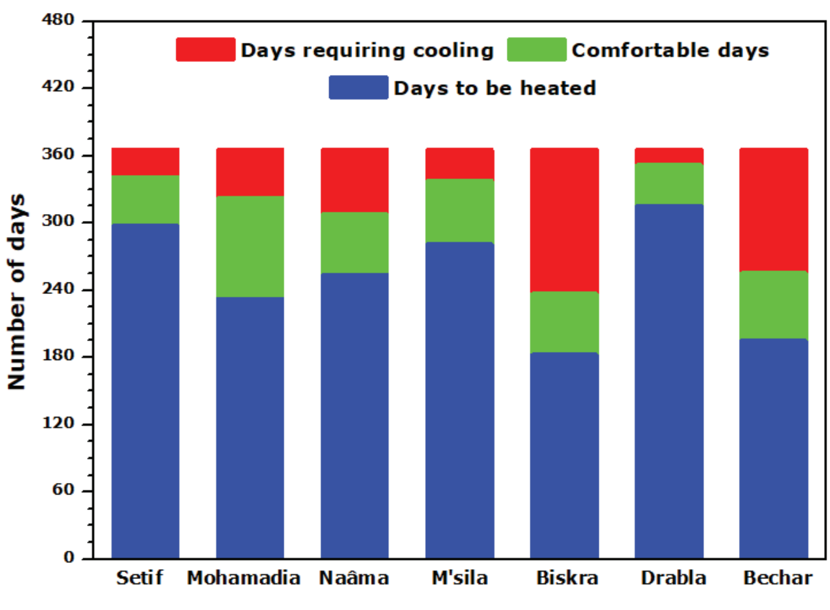

Figure 4. Average monthly temperatures for several climatic regions.

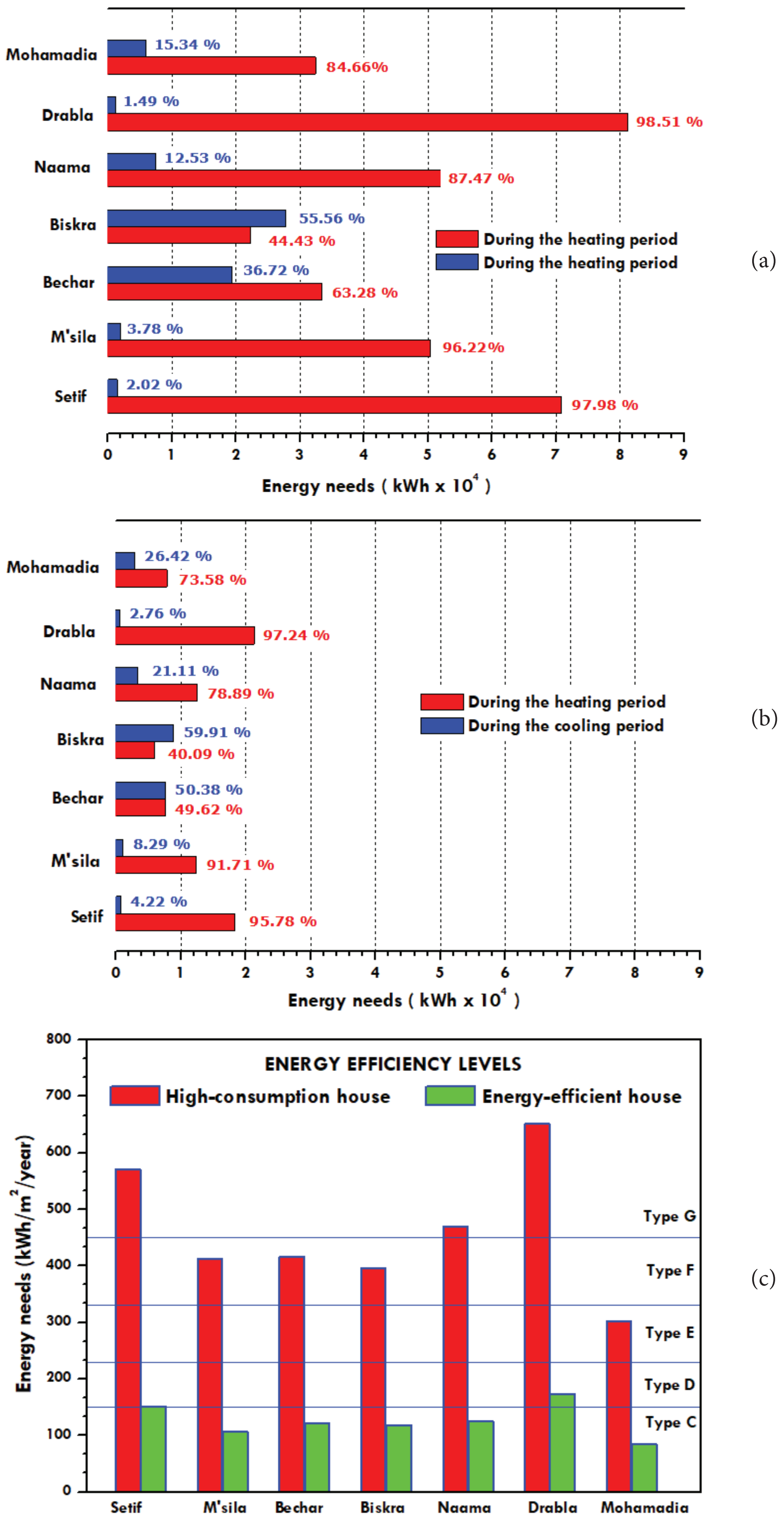

Figure 5. Energy efficiency assessment of the two buildings, a: monthly energy needs of the high-energy-use house, b: monthly energy needs of the energy-efficient house, c: annual energy needs and labeling of the two houses.

minimizing the overall energy needs to support purchasing power, improving the life quality for Algerians and fighting climate change. According to the obtained results, this approach has led to significant energy savings. It was referred to the specific energy rehabilitation ("D" or "C" labels), which is systematically applied to social contexts. The building envelope is the main source of the total energy needs. This time, the cost-effectiveness has been demonstrated. Total annual energy requirements are significantly reduced in the range from 70.33% in Biskra to 74.13% in M'sila. The best energy efficiency is observed in the coldest climate sites during the heating season. Heating energy savings are generally close and vary within a short range of 73.23%-77.33% compared with the initial energy demand. In overheating periods, energy savings are less noticeable than in cold periods. For the examples given, it was estimated at 44.89%, 43.24%, 60.34%, 68.01%, 55.28%, 50.63% and 51.95% for the regions of Sétif, M'sila, Béchar, Biskra, Naâma, Drabla and Mohamadia respectively.

Cost Estimates for Thermal Insulation Works

By following this schedule, an economic feasibility study, which will include market, technical and financial studies, seems more than necessary to serenely assess the viability of the rehabilitation project in the light of the economic context. To do this, calculating the monetary value of an investment according to its cost has become essential. The return on investment ROI will be selected to take these considerations into account. It is mainly based on the cost of thermal insulation work and the savings on energy bills. The increase in insulation thickness systematically leads to both an increase in financial expenditures dedicated to overall thermal insulation work, an improvement in thermal performance, and an increase in annual energy savings. If the rate of increase in energy gain is higher compared to the annual energy gain, the return on investment can be amortized. However, regardless of the situation, calculations must be made according to the case studies. An estimate of Algeria's financial expenditure on thermal insulation is given in Table 3 below.

Table 3. Financial expenditure on thermal insulation work for the case of this study

Work stages	Adopted methods, requirements and designation of tools and accessories	General notes	Total costs incurred in the operation
Manual brush cleaning of mortar facades	Manual drybrush cleaning	Qualified personnel are not required to apply it	14.15 €/m²
Repairing the facade cladding	With an alkaline and colorless detergent	- In this case, the finish coatings are flawless. - Requires a professional companion and an execution worker	4.64 €/m²
External thermal insulation of facades	Rigid expanded polystyrene panels, leveling accessory, supporting and capping insulation panels, compound mortar as a base coat for the trowel application and for bonding insulation panels, expansion dowels for fixing, anti-alkali fiberglass mesh for mortar reinforcement, PVC corner profile with mesh for edge reinforcement, acrylic mortar for coating external facings, expanded polyethylene cord, putty cartridge,… etc.	The rigid panel has a thickness of 10 cm. Requires: - Professional companion and an execution worker - Professional installer of rigid or flexible insulation panels - Professional coaters	74.81 €/m²
Thermal insulation of flat roofs on load-bearing masonry elements	Rigid expanded polystyrene panels, adhesive tape, fixing washers, adhesives for joints and connections, high-performance climatic membrane without armoring for maximum protection against moisture and vapor,… etc.	The rigid panel has a thickness of 10 cm. Requires: - Professional companion - Professional installer of rigid or flexible insulation panels	25.01 €/m²
Horizontal thermal insulation for flooring slabs	Rigid expanded polystyrene panels, polyethylene film, and self-adhesive tape for sealing joints	Compressive strength greater than 500 kPa The rigid panel has a thickness of 5 cm. Requires: - Professional companion - Professional installer of rigid or flexible insulation panels	19.88 €/m²

Energy Bill Analysis and Allocated Subsidies

In August 2024, the average price of electricity worldwide was 0.14 € per kWh. Liechtenstein is the country with the most expensive electricity, at 0.48 € per kWh, while the cheapest electricity in the world is in Iran, at 0.0018 € per kWh [29]. Algeria is also one of the few countries in the world where the price per kWh is cheaper than in other countries. According to the Algerian government, the real price per kWh is 0.1122 €. Subsidies to Algerian citizens exceed 60% in the northern regions and nearly 82% in the south. The regulated price therefore costs 0.0449 €/kWh in the north and 0.0202 €/kWh in the south [30]. However, energy consumption patterns have a huge impact on annual household bills. Natural gas is now widely used as a direct heat source for both space and domestic hot water due to its low installation costs and competitive regulated sales tariffs for homeowners. As for electricity, the Algerian Electricity and Gas Regulatory Commission has set the average price at 0.0023 €/Thermie, whereas the Real price is 0.0029 €/Thermie [30]. It is accepted that 1 kWh = 0.8598 Thermie. The estimated annual energy bills for the different scenarios are shown in Table 4 below. Rectangular cells of the same color should be compared for each mode. The first corresponds to the annual electricity bill of the house, excluding thermal rehabilitation measures and taking into account the financial support. In contrast to the first, the second refers to the annual housing bill with the inclusion of thermal rehabilitation measures and without financial assistance.

Table 4. Energy consumption and bills in all scenarios

Climate zone	First mode of energy consumption			Second mode of energy consumption		
	Energy consumption	Actual invoice (€)	Subsidized invoice (€)	Energy consumption	Actual invoice €	Subsidized invoice (€)
	Before thermal rehabilitation					
Setif	72 251.31 kWh	8 106.60	3 202.11	1 457.01 kWh 60 868.94 Thermie	340.00	204.57
M'sila	52 291.30 kWh	5 867.08	1 056.08	1 976.70 kWh 43 260.49 Thermie	347.24	179.92
Bechar	52 723.31 kWh	5 915.55	1 064.80	19 295.51 kWh 28 741.22 Thermie	2 248.30	179.91
Biskra	50 050.15 kWh	5 615.63	1 010.81	27 809.25 kWh 19 122.73 Thermie	3 175.65	179.92
Naâma	59 463.22 kWh	6 671.77	1 200.92	7 450.62 kWh 44 720.43 Thermie	965.65	179.92
Drabla	82 473.92 kWh	9 253.57	1 665.64	1 227.72 kWh 69 855.48 Thermie	340.33	179.92
Mohamadia	38 357.93 kWh	4 303.76	1 699.98	5 884.83 kWh 27 920.37 Thermie	741.25	227.60
	After thermal rehabilitation					
Setif	19 073.18 kWh	**2 140.01**	845.30	804.68 kWh 15 707.26 Thermie	**135.84**	71.79
M'sila	13 527.96 kWh	**1 517.84**	273.21	1 121.56 kWh 10 667.02 Thermie	**156.77**	58.78
Bechar	15 343.43 kWh	**1 721.53**	309.88	7 766.43 kWh 6 514.70 Thermie	**890.28**	58.78
Biskra	14 849.33 kWh	**1 666.09**	299.90	8 895.33 kWh 5 119.25 Thermie	**1 012.90**	58.78
Naâma	15 788.11 kWh	**1 771.43**	318.86	3 332.51 kWh 10 709.32 Thermie	**404.96**	58.78
Drabla	21 930.04 kWh	**2 460.55**	442.90	605.64 kWh 18 334.72 Thermie	**121.12**	58.78
Mohamadia	10 701.50 kWh	**1 200.71**	474.28	2 827.40 kWh 6 770.15 Thermie	**336.87**	85.83

First and foremost, the use of natural gas for heating, both for the production of domestic hot water and for space heating, is financially more favorable. The resulting energy bills are much lower, and the savings are very significant. Without thermal rehabilitation measures: excluding state subsidies, the tariffs are reduced from 94.08% to 96.32% in the regions around the Setif, M'sila and Drabla climatic zones, where the heating energy needs account for the overwhelming proportion of total requirements, as shown in Figure 5-a. At sites near the Mohamadia and Naâma climatic regions, financial expenditure will be reduced by more than 82.78% and less than 85.53% respectively. These regions are also characterized by high heating demand, but slightly less than the previous regions. However, the financial benefits are much lower in the Saharan regions which are characterized by higher energy demand due to summer air conditioning, such as Bechar and Biskra. They depend mainly on the share of the region's energy demand for air conditioning to its total energy demand. In the Bechar and Biskra climatic zones, the financial rationalization is equivalent to 61.99% and 43.45%, respectively. Moreover, in the case of social assistance, the combined use of electricity and gas leads to a very significant rationalization of expenditure, which can be as much as 93.61% in Setif, compared with the case where electricity would be the only source of energy to meet energy needs. For the remaining regions, the fare reduction rate varies between 82.20% and 86.61%.

In the case of thermal rehabilitation, the same observation is made for the bills corresponding to the regions surrounding the climatic sites of Setif, M'sila and Drabla, which are characterized by an overwhelming dominance of heating throughout the year, as shown in Figure 5b. Costs fell by more than 89.67% and less than 95.08%. However, in climatic regions similar to Mohamadia and Naâma, it is possible to minimize electricity bills by more than 71.94% and less than 77.14%. For climatic sites identical to those in Bechar and Biskra, financial savings of between 39.20% and 48.28% can be achieved. The financial benefits are much lower in the Saharan regions where summer air conditioning increases energy demand, such as Bechar and Biskra. They depend mainly on the proportion of the region's energy requirements for air conditioning according to its total energy requirements. The financial rationalization is equivalent to 61.99% and 43.45% for Bechar and Biskra respectively. In addition, when financial aid is available, such as in the cities of M'sila, Bechar, Biskra and Mohamadia, the combined use of electricity and gas promotes a very concrete minimization of financial expenditure, which is close to 80%. It can reach 91.52% and 86.73% at the Setif and Drabla sites respectively.

It should be remembered that all these estimates correspond to energy needs and electricity bills that are consistent with a comfort maintained 24 hours a day, 365 days a year, without interruption and in all zones. It should also be noted that the achieved results remain valid if the desired comfort conditions correspond to only a small area. The calculated values are relative and linearly proportional to the energy needs and the comfort requirements.

From a financial point of view, subsidies are significantly lower for lower cooling energy needs. On the other hand, in both cases, without and with thermal rehabilitation, it has been noted that the Algerian subsidy strategy, which allows partially improve the standard of living and social security, leads to a certain degree of social justice for the same housing conditions. In many cases, the invoice estimates are similar, if not identical.

The values shown in green mean that, by adopting these rehabilitation measures, unsubsidized energy bills are lower than those corresponding firstly to a conventional home without thermal rehabilitation and secondly to subsidized bills. Given this, it is systematically more judicious for the state to sell the electricity to citizens without recourse to subsidies. It will therefore be more appropriate to provide this financial aid, which will quickly pay for itself over time, to thermal rehabilitation measures. This becomes more apparent when electricity is used for cooling and natural gas for heating. On the other hand, red values mean that subsidies for thermal rehabilitation are insufficient. Unsubsidized energy bills are higher than those of a non-subsidized home and subsidized bills. Additional subsidies will therefore be needed to make up the difference in the bills.

In other respects, producing domestic hot water using solar energy from a properly sized heating system can be a good alternative. Experience has shown that use of the solar energy can cover a very large proportion of the annual hot water demand, given Ghardaïa's high solar potential. This can sometimes cover all the energy needed to produce it. In our case, a family of 5 in Ghardaïa needs an annual consumption of 3816.74 kWh. This case involves a flat-plate "Megasun" solar water collector with a total surface area of 2.61 m^2, fitted with a 200-litre storage tank and an electric pump. On a yearly basis, the average energy cost savings may reach up to 80.25% if optimal tilt for the solar collector is adopted every monthly. The flat plate collector may be vulnerable to convective heat transfer; therefore, other solar collectors, such as vacuum tube collectors, may provide enhanced energy performance [31]. In these regions, a 100-litre solar water heater may be sufficient for a house with several occupants, while in regions with less sunshine, a 300-litre model may be required for even a medium-sized house. The wisest method is to carry out a personalized study to determine which model of solar water heater is best suited to the specific needs. Including the equipment, the support structure and the labor, the total cost of this solar hot water system has been set at €6,000 including tax.

Financing a stand-alone photovoltaic system can also be a good alternative. Table 5 sets out relevant proposals for clarifying the precise destination and amount of subsidies, to completely avoid the injection of financial aid intended for the conventional electricity from the national grid. According to a recent study [32], on average, the total cost in Algeria of a technically and technologically reliable stand-alone photovoltaic system producing 5.5 kWh costs around 13 421 €. The estimated total cost of the whole installation increases linearly with the electrical load retained by users. An increase of 0.5 kWh in the supply load results in an additional investment of almost 1 200 €.

After analyzing the subsidies, it was found that the state can completely cancel the subsidies for conventional electricity by replacing them with a «Megasun» type solar water heater and a stand-alone photovoltaic system. The size of this system varies according to the climatic region. The financial assistance, corresponding to the first consumption mode, will cost between 13 036.91 € et 32 887.63 €. The most suitable regions, ranked according to merit, are M'sila, Naâma, Biskra, Bechar and, lastly, the Drabla

Table 5. State financial aid required to eliminate subsidies of the national grid electricity.

<table>
<tr><th>Climate zone</th><th colspan="3">First mode of energy consumption</th><th colspan="3">Second mode of energy consumption</th></tr>
<tr><td>Setif</td><td colspan="3">Subsidies for thermal rehabilitation measures are quite sufficient</td><td colspan="3">Subsidies for thermal rehabilitation measures are quite sufficient</td></tr>
<tr><td rowspan="2">M'sila</td><td colspan="3">Grant for rehabilitation measures + Grant of 461.76 € equivalent to 4 115.50 kWh/year i.e. to</td><td colspan="3" rowspan="2">Subsidies for thermal rehabilitation measures are quite sufficient</td></tr>
<tr><td>11.27 kWh/day of PV electricity which costs 27 514 €</td><td>or</td><td>3062.93 kWh/year from the solar water collector which costs 6 000 € and a PV system of 2.88 kWh/day which costs 7 036.91 €</td></tr>
<tr><td rowspan="2">Bechar</td><td colspan="3">Grant for rehabilitation measures + Grant of 656.73 € equivalent to 5 853.21 kWh/year i.e. to</td><td colspan="3">Grant for rehabilitation measures + subsidy of 710.37 € equivalent to 6 331.28 kWh/year or 2 633.51 Thermie/year and 6 263. 22 kWh/year, i.e. the subsidy of</td></tr>
<tr><td>16.04 kWh/day of PV electricity which costs 39 131 €</td><td>or</td><td>3062.93 kWh/year from the solar water collector which costs 6 000 € and a PV system of 7.64 kWh/day which costs 18 654.18 €</td><td>17.34 kWh/day of PV electricity which costs 42 327.35 €</td><td>or</td><td>solar water collector which costs 6 000 € and a PV system of 17.16 kWh/day which costs 41 872.29 €</td></tr>
<tr><td rowspan="2">Biskra</td><td colspan="3">Grant for rehabilitation measures + Grant of 655.28 € equivalent to 5 840.29 kWh/year i.e. to</td><td colspan="3">Grant for rehabilitation measures + subsidy of 832.98 € equivalent to 7 424.06 kWh/year or 2 633.51 Thermie/year and 7 356 kWh/year, i.e. the subsidy of</td></tr>
<tr><td>16 kWh/day of PV electricity which costs 39 045 €</td><td>or</td><td>3062.93 kWh/year from the solar water collector which costs 6 000 € and a PV system of 7.61 kWh/day which costs 18 567.79 €</td><td>20.34 kWh/day of PV electricity which costs 49 633.06 €</td><td>or</td><td>solar water collector which costs 6 000 € and a PV system of 20.15 kWh/day which costs 49 178.00 €</td></tr>
<tr><td rowspan="2">Naâma</td><td colspan="3">Grant for rehabilitation measures + Grant of 570.51 € equivalent to 5 084.76 kWh/year i.e. to</td><td colspan="3">Grant for rehabilitation measures + subsidy of 225.04 € equivalent to 2 005.70 kWh/year or 2 633.51 Thermie/year and 1 937.64 kWh/year, i.e. the subsidy of</td></tr>
<tr><td>13.93 kWh/day of PV electricity which costs 33 993.80 €</td><td>or</td><td>3062.93 kWh/year from the solar water collector which costs 6 000 € and a PV system of 5.54 kWh/day which costs 13 516.77 €</td><td>5.49 kWh/day of PV electricity which costs 13 408.99 €</td><td>or</td><td>solar water collector which costs 6 000 € and a PV system of 5.31 kWh/day which costs 12 953.93 €</td></tr>
<tr><td rowspan="2">Drabla</td><td colspan="3">Grant for rehabilitation measures + Grant of 794.91 € equivalent to 7 084.76 kWh/year i.e. to</td><td colspan="3" rowspan="2">Subsidies for thermal rehabilitation measures are quite sufficient</td></tr>
<tr><td>19.41 kWh/day of PV electricity which costs 47 364.66 €</td><td>or</td><td>3062.93 kWh/year from the solar water collector which costs 6 000 € and a PV system of 11.02 kWh/day which costs 26 887.63 €</td></tr>
<tr><td rowspan="2">Mohamadia</td><td colspan="3" rowspan="2">Subsidies for thermal rehabilitation measures are quite sufficient</td><td colspan="3">Grant for rehabilitation measures + subsidy of 109.27 € equivalent to 973.88 kWh/year or 2 633.51 Thermie/year and 905.81 kWh/year, i.e. the subsidy of</td></tr>
<tr><td>2.67 kWh/day of PV electricity which costs 6 510.84 €</td><td>or</td><td>solar water collector which costs 6 000 € and a PV system of 2.48 kWh/day which costs 6 055.78 €</td></tr>
</table>

climatic region. These results remain valid even in the case of the second consumption mode, which corresponds to the climatic regions of Naâma and Mohamadia. In the climates of Bechar and Biskra, which are characterized by high levels of air conditioning, it will be very expensive to spend more than 40 000 €. In these circumstances, other alternatives need to be sought. The cost of the thermal rehabilitation is estimated at 17 167.99 €.

Return on investment «ROI» is a measure of the percentage return on investment by considering the amount of money that has been invested. The costs and the benefits of these future solutions will then need to be assessed. These will determine the viability of the used energy concepts. The change in this indicator number, expressed by the number of months, depends on the ratio between the additional cost multiplied by 12 and the annual financial gain. By definition, the extra cost is the difference between the final price (estimated investment cost + final annual electricity bill) and the initial price (initial annual electricity bill). The annual financial gain is calculated as the difference between the initial and the final electricity bill. As shown in Table 6, the results for the first case yielded the following estimates.

The return on investment is favorable, very acceptable and sometimes attractive, especially for climatic regions similar to Setif and Drabla. But, in the second case, the return on investment is unsuitable in most climatic sites, the financial gain is generally very low compared with the additional cost, ranging from 1.12% to 3.08%. On the contrary, the financial profitability is acceptable in Biskra and under climatic conditions that are similar to those of this region, but it is less so for the Bechar site.

If the investment covers, in addition to the rehabilitation of the building envelope, a solar water heater and a stand-alone photovoltaic system, the results give the following estimates, as shown in Table 7.

According to the results, the cost-effectiveness of the involved measures can be considered very acceptable, but on the condition that the solar battery bank has a satisfactory lifetime. Even though solar batteries have a very limited lifespan, typically between 5 and 10 years (this is the case for AGM solar batteries, for example), the adoption of these energy concepts is still economically and financially viable. In more complicated circumstances, and for greater profitability, the user should select high-performance solar batteries such as gel batteries, which withstand an average of 900 cycles, or lithium-ion batteries, which offer the greatest durability, with up to 3000 cycles, representing up to 15 years of use. Furthermore, for the second consumption mode, the subsidy method did not bring a return on financial expenditure, but it did allow a significant reduction in annual energy requirements.

Table 6. Return on Investment from the thermal rehabilitation of the house

Climatic region	Initial electricity bill (€)	Electricity bill for the energy-saving house (€)	Annual financial gain (€)	Extra cost (€)	Annual financial gain compared to the extra costs (%)	Return on investment		
						Number of years	Number of months	Number of days
Case of the first consumption mode								
Setif	8 106.60	2 140.01	5 966.59	11 201.40	53.27	1	10	16
M'sila	5 867.08	1 517.84	4 349.24	12 818.75	33.93	2	11	11
Bechar	5 915.55	1 721.53	4 194.02	12 973.97	32.33	3	1	4
Biskra	5 615.63	1 666.09	3 949.54	13 218.45	29.88	3	4	5
Naâma	6 671.77	1 771.43	4 900.34	12 267.65	39.94	2	6	1
Drabla	9 253.57	2 460.55	6 793.02	10 374.97	65.47	1	6	10
Mohamadia	4 303.76	1 200.71	3 103.05	14 064.94	22.06	4	6	12
Case of the second consumption mode								
Setif	340.00	135.84	204.16	16 963.83	1.20	83	1	3
M'sila	347.24	156.77	190.47	16 977.52	1.12	89	1	19
Bechar	2 248.30	890.28	1 358.02	15 809.97	8.59	11	7	21
Biskra	3 175.65	1 012.90	2 162.75	15 005.24	14.41	6	11	8
Naâma	965.65	404.96	560.69	16 607.30	3.38	29	7	13
Drabla	340.33	121.12	219.21	16 948.78	1.29	77	3	24
Mohamadia	741.25	336.87	404.38	16 763.61	2.41	41	5	14

Table 7. Return on investment by thermally renovating the house and integrating a stand-alone photovoltaic system and solar hot water.

Climatic region	Initial electricity bill (€)	Electricity bill for the energy-saving house (€)	Annual financial gain (€)	Extra cost (€)	Annual financial gain compared to the extra costs (%)	Return on investment		
						Number of years	Number of months	Number of days
Case of the first consumption mode								
Setif	8 106.60	2 140.01	5 966.59	11 201.40	53.27	1	10	16
M'sila	5 867.08	1 517.84	4 349.24	25 855.66	16.82	5	11	10
Bechar	5 915.55	1 721.53	4 194.02	37 628.15	11.14	8	11	20
Biskra	5 615.63	1 666.09	3 949.54	37 786.24	10.45	9	6	24
Naâma	6 671.77	1 771.43	4 900.34	31 784.42	15.41	6	5	25
Drabla	9 253.57	2 460.55	6 793.02	43 262.60	15.70	6	4	13
Mohamadia	4 303.76	1 200.71	3 103.05	14 064.94	22.06	4	6	12
Case of the second consumption mode								
Setif	340.00	135.84	204.16	16 963.83	1.20	83	1	3
M'sila	347.24	156.77	190.47	16 977.52	1.12	89	1	19
Bechar	2 248.30	890.28	1 358.02	63 682.26	2.13	46	10	22
Biskra	3 175.65	1 012.90	2 162.75	70 183.24	3.08	32	5	28
Naâma	965.65	404.96	560.69	35 561.23	1.58	63	5	2
Drabla	340.33	121.12	219.21	16 948.78	1.29	77	3	24
Mohamadia	741.25	336.87	404.38	28 819.39	1.40	71	3	7

CONCLUSION

Energy products, including electricity and gas, took the lion's share of the state budget allocated to subsidies, accounting for 85% of total subsidies. In 2021, the average selling price of natural gas on international markets (5.8 $ per unit of measurement) was 30 times higher than the local price (0.19 $ per unit of measurement). To deal with this distressing problem, the conclusions reached lead us to deduce that the current subsidy system will not have to be fully maintained. Reducing or eliminating electricity subsidies is a complex process that requires careful planning and a systematic approach. It first necessitated an analysis of existing subsidies by identifying their cost and impact on the national budget. The reasons for reducing or eliminating subsidies, the proposed alternatives, the economic consequences including the impact on electricity prices and the adjustment of policies according to needs and concerns have become of paramount importance. It is preferable to abolish a large proportion of these subsidies and then offset them by adopting other incentives such as :

- Subsidizing the financial costs of integrating passive architectural measures, while carrying out a rehabilitation or even a thermal retrofit in favor of non-energy-efficient buildings. This mechanism presents a basic solution. By adopting these rehabilitation measures, unsubsidized energy bills are lower than those corresponding firstly to a conventional home without thermal rehabilitation and secondly to subsidized bills.
- Promoting and relaunching a subsidy program for solar water heaters.
- Adopting a subsidy program for residential photovoltaic systems, which appears to be a major challenge for environmentally sustainable urban development.
- Raising public awareness, highlighting the importance of simple gestures and energy-saving measures, and promoting new ideas or solutions to this problematic situation.

Whatever the energy consumption mode, the subsidies allocated to thermal rehabilitation are largely sufficient in the case of housing located in climatic regions similar to Setif. This means that subsidies for conventional grid electricity can be permanently eliminated and offset. This result is also confirmed for buildings, subject to the first consumption mode and corresponding to climatic regions similar to that of Mohamadia. The same conclusion can be drawn for buildings that are subject to the second consumption mode, but which correspond to climatic regions similar to those of Drabla and M'sila. For the first mode, the payback period of the operation is very attractive, estimated at less than 2 years in Sétif and 4.5 years for the Mohamadia region. On the other hand, in all other climatic regions, the return on investment, which covers the thermal rehabilitation operation, a solar water heater and a stand-alone photovoltaic system, is still attractive if the first consumption mode is followed. However, the return on investment, covering the thermal rehabilitation operation, is very favorable in the case of the climatic regions of Biskra and globally acceptable in the case of climatic regions similar to those of Bechar. In the remaining cases, the return on investment has not lived up to expectations.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

NOMENCLATURE

Con_{Env}	Energy consumption due to the building envelope (Wh)
$Hlos_{Ventilation}$	Heat loss from the ventilation system and each element (W/K)
Con_{DHW}	Average energy requirement for daily water heating (Wh)
Vol_{DHW}	Amount of domestic hot water required for the user's use (liters).
T_{DHW}	Temperature of the domestic hot water (°C)
T_{CW}	Temperature of the cold water (°C)
$Nb_{Residents}$	Number of residents occupying the building
$\varphi_{Occupants}$	Heat flux released by the human body per occupant (W)
Nb_{Days}	Number of days to be heated / cooling
$Dur_{Residents}$	Mean duration of the resident presence per occupant (hours per day)
$Hg_{Lighting/Other}$	Heat flux released by lighting, electrical appliances, devices and significant usage of equipment, cooking, etc (W)
$Dur_{In\ operation}$	Total run time of the lighting system and all equipment to be powered (hours per day)
n	Number of the transparent opening fronts
I_j	Daily solar irradiance incident on a unit surface of orientation j (Wh/m^2)
$A_n(j)$	Equivalent receiving surface (sum of surfaces of transparent opening fronts) of an orientation j
$Aop_n(j)$	Opening area (m^2) corresponding to the window n of the orientation j.
$Fs_n(j)$	Shading correction factor according to the orientation j.
S	Solar factor for windows n of the orientation j.
P_{Elec}	Electrical power of equipment (W).

Greek symbols

ρ	Water density (kg/liter)

REFERENCES

[1] Manić DJ, Komatina MS, Vučićević BS, Jovanović MP. Energy performance of single family houses in Serbia: analzsis of calculation procedures. Therm Sci 2019;23:1695−1705. [CrossRef]
[2] Šumarac DM, Todorović MN, Djurović-petrović MD, Trišović NR. Energy Efficiency of Residential Buildings in Serbia. Therm Sci 2010;14:97−113. [CrossRef]
[3] Djurov-Petrović MD, Lazarević AD, Kojičić BZ. Integration of the energy efficiency into the local development strategies. Therm Sci 2018;22:1297−1310. [CrossRef]
[4] Luo C, Gong Y, Weibin MA, Zhao J. Building energy efficiency in Guangdong province, China. Therm Sci 23 2019;23:3251−3262. [CrossRef]
[5] Canbolat AS, Bademlioglu AH, Saka K, Kaynakli O. Investigation of parameters affecting the optimum thermal insulation thickness for buildings in hot and cold climates. Therm Sci 2020;24:289 −2903. [CrossRef]
[6] Shahid M, Karimi MN. Optimization of energy transmittance through building envelope for hot dry climate. J Therm Eng 2022;8:595−605. [CrossRef]
[7] Aktemur C, Bilgin F, Tunckol S. Optimisation on the thermal insulation layer thickness in buildings with environmental analysis: an updated comprehensive study for Turkey's all provinces. J Therm Eng 2021;7:1239−1256. [CrossRef]
[8] Bentoumi L, Bouacida T, Bessaih R, Bouttout A. Impact of thermal insulation on energy consumption in buildings. J Therm Eng 2024;10:924−935. [CrossRef]
[9] Ziad S, Benoudjafer I, Benoudjafer I. Towards the use of natural thermal insulation on the exterior of vertical building walls in desert regions: A case study in the city of Bechar, Algeria. J Therm Eng 2024;10:308−320. [CrossRef]

[10] Canbolat AS. An integrated assessment of the financial and environmental impacts of exterior building insulation application. J Clean Prod 2024;435:140376. [CrossRef]
[11] Dorri A. Energy Efficiency Analysis in Korça Regional Hospital. Int J Innovative Technol Interdiscip Sci 2023;6:1121–1129. [CrossRef]
[12] Adamczyk J, Dylewski R, Sobierajewicz P. Ejconomic and ecological benefits of thermal insulation of external partitions depending on the temperature in residential premises. J Clean Prod 2023;384:135622. [CrossRef]
[13] Dylewski R, Adamczyk J. Economic and ecological indicators for thermal insulating building investments. Energy Build 2012;54:88–95. [CrossRef]
[14] Adamczyk J, Dylewski R. The impact of thermal insulation investments on sustainability in the construction sector. Renew Sustain Energy Rev 2017;80:421–429. [CrossRef]
[15] AIE. Fossil Fuels Consumption Subsidies 2022. Available at: https://www.connaissancedesenergies.org/energies-fossiles-les-subventions-mondiales-la-consommation-ont-atteint-un-niveau-record-en-2022-240426#notes. Accessed on 5 Mar 2026.
[16] Finon D. Les subventions à l'énergie dans le monde : leur ampleur, leur efficacité et leur nécessaire recentrage. Available at: https://inis.iaea.org/records/zbbry-6nb11/files/43038274.pdf?download=1. Accessed on 5 Mar 2026.
[17] Benkhelifa A. Thermo-aéraulique d'un bâtiment multizone & Influence de la compacité par rapport à la taille des murs à forme constante. Available at: http://dspace.univ-tiaret.dz/bitstream/123456789/14619/1/Th%C3%A8se%20de%20Doctorat%20Benkhelifa%20Abdelaziz%20%20%20%2008%20juin%202024.pdf. Accessed on 5 Mar 2026.
[18] Bensaha A. Exploitation d'énergies renouvelables pour la conception d'un habitat durable dans un site isolé en zone semi-aride : Cas de l'Algérie, Ph. D. thesis, Amar Telidji University, Laghouat, Algeria, 2021
[19] Benkhelifa A, Bekkouche SMA, Allaoui T, Cherier MK, Hamdani M, Mihoub R, et al. Application of the building height concept to energy-efficient heating and cooling for Saharan buildings. Int Inf Eng Technol Assoc 2022;80:71–78. [CrossRef]
[20] Bendara S, Bekkouche SMA, Benouaz T, Belaid S, Hamdani M, Cherier MK, et al. Energy efficiency and economic insulation thickness according to the compactness measure case of a studio apartment under Saharan weather conditions. J Solar Energy Eng2017;141:1–11. [CrossRef]
[21] Belgherras S, Bekkouche SMA, Benouaz T, Benamrane N. Prospective analysis of the energy efficiency in a farm studio under Saharan weather conditions. Energy Build 2017;145:342–353. [CrossRef]
[22] Bekkouche SMA, Benouaz T, Hamdani M, Cherier MK, Yaiche MR, Benamrane N. Diagnosis and comprehensive quantification of energy needs for existing residential buildings under Sahara weather conditions. Adv Build Energy Res 2017;11:37–51. [CrossRef]
[23] Kadraoui H, Bekkouche SMA, Chikhaoui A. Analysis of energy consumption for Algerian building in extreme North-African climates. Int J Sustain Energy Plan Manag 2019;19:45–58.
[24] Densité de l'eau en fonction de la température. Available at: http://www.atomer.fr/1/1-densite-eau.html. Accessed on 5 Mar 2026.
[25] Kottek M, Grieser J, Beck C, Rudolf B, Rubel F. World Map of the Köppen-Geiger climate classification updated. Meteorol Z 2006;15:259–263. [CrossRef]
[26] Wikipédia. Classification de Köppen. Available at: https://fr.wikipedia.org/wiki/Classification_de_K%C3%B6ppen, Accessed on 5 Mar 2026.
[27] Belda M, Holtanová E, Halenka T, Kalvová J. Climate classification revisited: from Köppen to Trewartha. Clim Res 2014;59:1–13. [CrossRef]
[28] ADEME. Comment garder son logement frais en été ?. Available at: https://www.netatmo.com/fr-fr/comfort-guide/air-conditioning-ideal-temperature. Accessed on 5 Mar 2026.
[29] Prix de l'électricité dans le monde : où se situe la France?. Available at: https://www.fournisseurs-electricite.com/contrat-electricite/prix/monde. Accessed on 5 Mar 2026.
[30] GlobalPetrolPrices. Algérie prix du gaz naturel. Available at: https://fr.globalpetrolprices.com/Algeria/natural_gas_prices/. Accessed on 5 Mar 2026.
[31] Bekkouche SMA, Djeffal R, Cherier MK, Hamdani M, Younsi Z, Al-Saadi S, et al. Experimental performance and cost-effectiveness of a combined heating system under saharan climate. Building 2023;11:1–27. [CrossRef]
[32] Morceli A, Temmar A. Taux et possibilités d'intégration de l'énergie photovoltaïque: Application à deux maisons individuelles à faible et à forte performance énergétique. Avaialble at: https://dspace.univ-ghardaia.edu.dz/xmlui/handle/123456789/9003. Accessed on 5 Mar 2026.