AIMS Energy

AIMS Energy, 11(3): 454–485.
DOI: 10.3934/energy.2023024
Received: 12 January 2023
Revised: 22 April 2023
Accepted: 25 April 2023
Published: 11 May 2023

http://www.aimspress.com/journal/energy

Review

Activity and efficiency of the building sector in Morocco: A review of status and measures in Ifrane

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Abstract: One-third of all greenhouse gas emissions come from the world's building stock while accounting for 40% of global energy use. There is no way to combat global warming or attain energy independence without addressing the inefficiency of the building sector. This sector is the second consumer of electricity after the industrial sector in Morocco and is ranked third emitter after the energy sector and transportation sector. Using Ifrane as a case study, this paper examines and reviews the city's energy use and the initiatives taken to improve building efficiency. The findings showed that, during the analyzed period, i.e., from 2014 to 2022, Ifrane's annual electricity consumption climbed steadily from 35 to 43 GWh. The government of Morocco has implemented effective laws, guidelines and regulations, as well as publicized ways to reduce energy consumption and increase energy efficiency. However, gathered data and survey results revealed opportunities and challenges for enhancing Ifrane's efficient energy use.

The study also evaluates government programs, codes/standards and related actions for the improvement of household energy efficiency. As part of the review, the available literature was analyzed to assess the effectiveness of energy behavior and awareness, the impact of an economical and sustainable building envelope, the impact of building retrofitting programs, the importance of energy-performing devices and appliances, the adoption of smart home energy management systems, the integration of renewable energies for on-site clean energy generation and the role of policies and governance in the building sector in Ifrane. A benchmark evaluation and potential ideas are offered to guide energy policies and improve energy efficiency in Ifrane and other cities within the same climate zone.

Keywords: building energy efficiency; low-energy building; consumption behavior; review paper; Morocco; Ifrane; sustainable cities; energy policy

1. Introduction

Energy efficiency is a key sustainability tenet that must be incorporated into a city to eliminate unnecessary energy waste, and as a knowledge-based city, sustainability must permeate every element of life there [1–3]. Increasing the efficiency of a system to produce the same amount of work with less energy is what is called energy efficiency. This idea allows for the enhancement of current systems to boost performance across technical, economic and ecological dimensions. Decreases in the energy sector's reliance on foreign sources and the number of potential threats are other benefits of increasing energy efficiency [4,5]. This latter is vital in cities in four main sectors: buildings, industries, transportation and public lighting.

Recent years have seen a rise in the number of studies looking at city-by-city energy usage and encouraging the development of sustainable-energy cities [6–8]. Some studies [9–13] have yielded several important guidelines for enhancing city dwellers' ability to save energy, and the increased use of efficient buildings is a good place to start [10,14,15].

Most of the energy used in cities goes toward powering structures. Buildings in Morocco are responsible for 24% of the country's CO_2 equivalent emissions, which is a relatively important share compared to other sectors, like the energy sector, which accounts for 40% [16]. Buildings are ranked as the third emitters after the energy and transportation sectors, respectively [17]. In Ifrane, according to 2021 data, buildings contribute to 62% of total energy consumption; Ifrane is the city with the highest building energy demand in Morocco, with 78.1 kWh/m² per year, followed by Marrakesh buildings, which consume 74.2 kWh/m² a year [16,18]. Therefore, building energy efficiency in Ifrane will be more effective from an operational and managerial perspective and could be referred to as a reference case study for other cities in the kingdom.

Ifrane is a town in the central-northern region of Morocco. It was established in 1929 and is home to some of the best winter and summer resorts in all of Morocco. At an elevation of about 1,650 m (5,400 ft), this contemporary town welcomes visitors from all over the world. Ifrane has been named one of the cleanest cities in the world and has been praised for its air quality and water quality. However, due to the high urbanization rate in the Middle Atlas, further precautions and actions should be done on the level of energy efficiency to meet the energy needs of the population and maintain the label of green city in Ifrane. When examining the policy aspect, it becomes apparent that there is an increasing amount of policies and tactics being put forth, urging action to be taken at the local, regional, national and worldwide scales. Morocco has implemented various policies and initiatives at both the regional and national levels since 2008, aimed at decreasing energy consumption in the building sector. These policies include eco-design [19], energy labeling [20], information drive [16], building energy performance [21] and energy efficiency guidelines [22]. Therefore, the aim of this paper is to present a thorough evaluation of the measures implemented in the building sector and propose potential solutions based on up-to-date data on the current state of affairs.

The bibliography of this article was chosen based on the following criteria: (i) strong correlation with the topic of the review article, (ii) strong connection with sub-topics of the research, (iii) human capital development (economic conditions that are important in ensuring sustainability) and (iv) public interest (to enable critical reviews to be conducted). This study examined over a hundred distinct sources, mainly reports and journal articles, on the notion of energy efficiency in buildings. Despite the gathered research, the authors noticed a lack of urban case studies on sustainable energy consumption, especially those of green buildings in Africa. The results of case studies could be utilized as examples of successful sustainable urban planning in different cities in countries with similar characteristics. The goals of this study were to conduct a critical examination of the energy efficiency measures implemented in Morocco and present an analysis of the energy strategies that the construction industry must adopt to mitigate the ecological consequences of urban areas in Morocco, specifically in Ifrane. The article is composed of four chapters; the second chapter covers the conservation of energy in buildings; the third chapter encompasses the important key factors and a roadmap for improving building energy efficiency in Ifrane. The fourth and fifth chapters are dedicated to discussions and conclusions, respectively. Figure 1 summarizes the framework of the energy efficiency topics and drivers discussed in the paper.

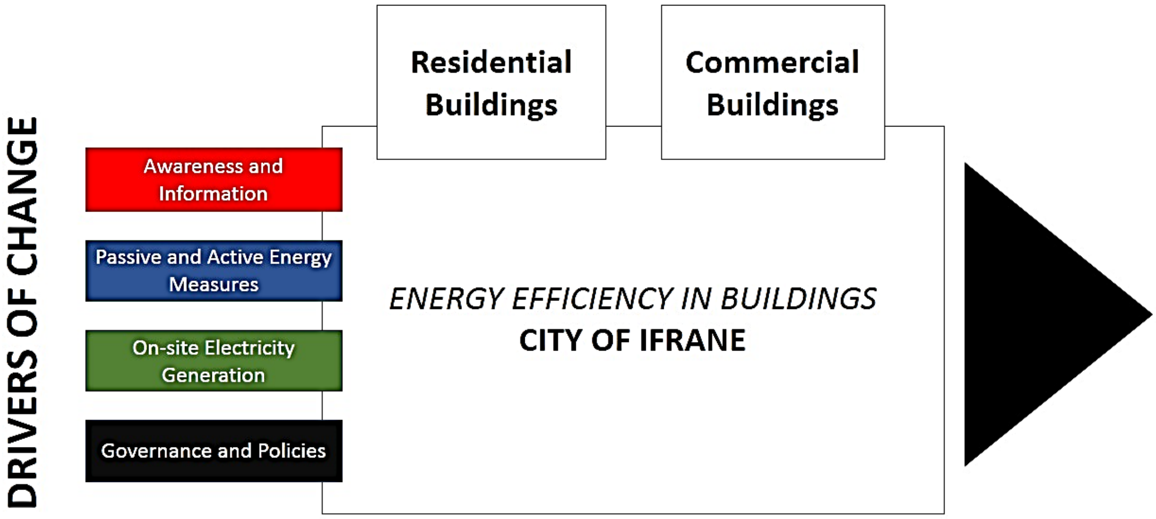

Figure 1. Framework of paper structure.

2. Conservation of energy in buildings

Many factors, including orientation, ventilation, thermal qualities of the envelope, occupant behavior and system efficiency, contribute to the overall energy requirements of buildings throughout construction and operation. Shade provided by neighboring features in urban areas is an example of an additional external site factor that should not be overlooked. Scientists in Morocco have undertaken numerous numerical and experimental studies on energy efficiency as it relates to the construction industry. Studies like these are conducted to decrease the need for heating and cooling. Sghiouri et al. [23] examined how an optimal overhang affects building energy savings and thermal comfort in three climates. The adjusted overhangs reduced Casablanca's Mediterranean climate's cooling requirement by 4.1%, improving thermal comfort and energy performance. Jihad and Tahiri [24] predicted residential building energy demand in the Atlantic climate of Agadir, South Morocco. The results revealed that artificial neural network outputs match computed values with 98.7% accuracy for prediction and 97.6%

accuracy for test data. Romani et al. [25] created and verified meta-models of single-family house heating and cooling energy demand in six Moroccan climates. This strategy successfully optimized the building envelope for rapid low-energy construction deployment in Morocco. Four passive cooling strategies, including cool painting, overhangs, reflective insulation and automated motorized shades, were tested for their impact on thermal comfort and energy performance in a Moroccan villa-style building constructed of clay-straw bricks by Sghiouri et al. [26]. Based on the data, it appears that, in Morocco, using each passive strategy evaluated in isolation is more beneficial than using any of them together. According to the research of Bendara et al. [27], thermal insulation is a viable option. However, the overall effectiveness of the package is enhanced by having a high level of compactness and boosting efficiency, particularly in structures with improved thermal insulation. Finally, a smaller footprint can save nearly 7.29% on the overall cost, and less on maintenance, albeit with a slightly longer return on investment time.

From the authors' research and outlook, there is a shortage of papers on active energy efficiency in buildings in Morocco. Rochd et al. [28] implemented a home energy management system in Green Park, Benguerir to schedule, power, monitor and control home appliances and HVAC systems within the house. The results of their study validate the effectiveness of home energy management systems and their impact on active energy efficiency in buildings. Lebied et al. [29] discussed the impacts of the actual Moroccan thermal building regulations. The authors, using TRNSYS, analyzed the influence of building shell parameters on heating/cooling demand per region in Morocco. The results in Ifrane, in particular, allowed for a gain in energy bills of USD 3.4 per square meter. Bouhal et al. [30] assessed the technical and economic aspects of using solar heating/cooling systems in residential buildings in Morocco. The results revealed the energy savings and benefits of using such a system, but also demonstrated the economic barriers and challenges facing their implementation in Morocco, as the payback period might not be appealing when considering the investment cost. Indeed, up to this date, no paper in Morocco has discussed or provided data about consumer behavior in Morocco; hence, this research is the first to study occupants and their behavior in the kingdom.

Since 2008, Morocco has introduced several regional and national policies and initiatives to control energy behavior and reduce energy consumption in the building sector. These measures include eco-design, energy labeling, information campaigns, building energy performance standards and energy efficiency guidelines. We aim to comprehensively evaluate the impact of these measures in the building sector through a case study of Ifrane, which has the highest energy demand per square meter among Moroccan cities. The evaluation approach and proposed solutions could serve as a benchmark for other cities in Morocco.

2.1. Residential buildings in Ifrane

2.1.1. Electricity consumption

Decision-makers in the field of building energy retrofitting should prioritize modeling energy consumption connected to structures at the city or district scale. Home energy usage can be modeled using either a top-down or bottom-up approach. The top-down methodology treats the building sector as a diffuser of energy and ignores the fact that different uses of energy have different impacts. Calculating the impact of structural shifts and technological innovations on home energy consumption is the primary goal of this model. The bottom-up methodology, on the other hand, encompasses all models that take in data from a hierarchical level below that of the sector as a whole, and it pinpoints how much energy is used for each end use [31,32].

To model energy use at the city scale, a building portfolio with various uses and consumption patterns must be included. Howard et al. [33] categorized urban buildings into eight types and used multiple linear regression to estimate New York building energy use, finding minimal discrepancies due to occupancy patterns, appliances and building configuration. Pereira and Sad de Assis [34] utilized energy planning to predict household energy consumption in different urban areas, finding that residential energy usage is linked to user household profiles and economic income levels. Mutani and Todeschi [35] evaluated the energy performance of residential buildings with an urban-scale energy model, designed an urban energy atlas for Turin, Italy and identified effective retrofitting interventions. Todeschi et al. [36] compared the accuracy and flexibility of a machine learning model and a geographic information system model for simulating the hourly space heating consumption of residential buildings in an urban environment, finding both models to be relatively accurate with annual mean absolute percentage errors of 12.8% and 19.3%, respectively.

The city of Ifrane is estimated to have a population of 15,944 [37] in 2022, covering an area of 4.25 km^2 [38]. In the absence of buildings' energy consumption data in the city, the authors decided to resort to bottom-up energy modeling by taking into consideration heating and cooling demand [16,19,39] and energy use from home appliances. Figure 2 displays the number of buildings by category. Indeed, there are 10 hotels in Ifrane. Indeed, there are 10 hotels in Ifrane, but some hotels include more than one building, with a sum of 61 buildings. Business and offices (governmental and private) have been counted to be 132 buildings in the city of Ifrane. As for educational buildings, only Al Akhawayn University has about 46 buildings on and off of the campus, which constitutes about 71% of the total educational buildings in Ifrane. Finally, residential buildings are 814 buildings in total, including villas (10.1%), apartments (23.4%), traditional houses (8.8%), modern houses (57.3%) and slums (0.4%).

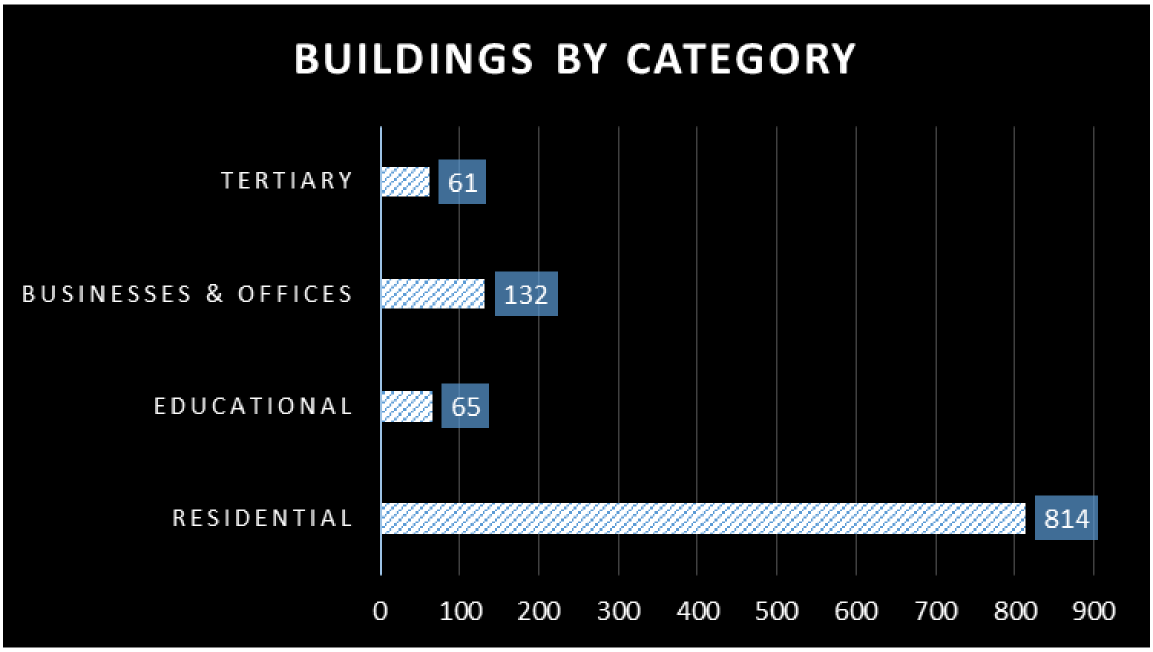

Figure 2. Buildings by category in the city of Ifrane.

Residential buildings constitute 76% of total buildings in Ifrane; they consume, on average, a total of 333.6 MWh per month, with a cost of USD 46,082 per month. To efficiently study residential buildings, the authors collected daily and monthly energy consumption from the National Office of Electricity, and shown in Figure 3 is the average daily energy consumption of a typical residential building in Ifrane from a supervised learning model in MATLAB. From the figure, maximum energy consumption happens at night between 7 PM and 11 PM, while minimum energy consumption occurs between 2 AM and 6 AM.

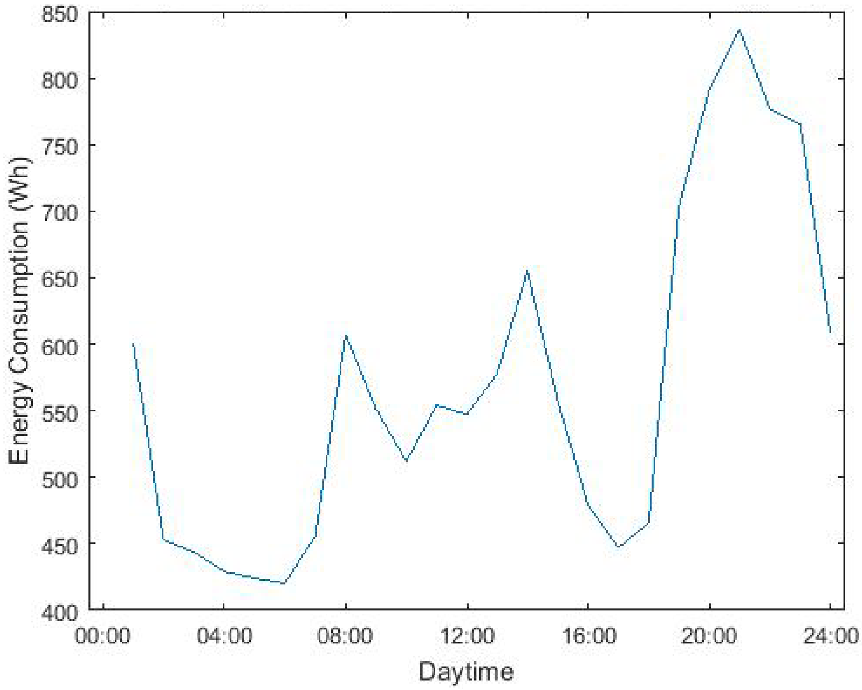

Figure 3. Daily electricity consumption for a unit residential building in Watt-hours.

2.1.2. Energy behavior and awareness

To explain Figure 3, it is necessary to understand consumers' behaviors and the technical details of home appliances for every residential building category; therefore, surveys were conducted, and residents from 58 residential buildings took the survey, from which 21% were villas, 28% were apartments, 23% were modern houses, 5% were slums and 23% were traditional houses. The ratio of slums was little, as there are only three slums in Ifrane. The results for frequently used equipment and their average use duration are summarized in Table 1. The surveys were used to calculate appliance saturation, whereas the nominal power can be accessed on the web pages of the respective manufacturers. The limited prevalence of appliances like ovens and backup heaters can be attributed to the fact that most Ifrane residents use gas and firewood heaters for both heating and cooking during the snowy and harsh winter months; this part will be further discussed in the next section. High smartphone and 3G/4G network penetration, low income and a lack of interest in certain household appliances, such as hair dryers and washing machines, are also factors in the low saturation of laptops and desktops.

Table 1. Common appliances details in residential buildings in Ifrane, Morocco.

Appliance	Average Units per Building	Penetration Rate	Nominal Wattage (W)	Time Use per Day (min)
TV	1.2	100%	130	102
Gaming Console	0.15	12.4%	210	20
Fridge	1.09	100%	350	480
Chest Freezer	0.11	9.9%	250	1048
Oven	0.13	13.2%	2200	8
Microwave	0.62	60.4%	700	3
Washing Machine	0.37	35.8%	1120	14
LED Bulbs	2.75	39.0%	9	194
Incandescent Bulb	7.91	93.8%	60	326
Fluorescent Lamps	2.13	22.1%	15	82
Iron	0.64	28.5%	920	1
Hair Dryer	0.86	52.0%	1800	23
Hair Straightener	0.91	49.7%	130	33
Phone Charger	2.31	100%	7	418
Laptop/Desktop	0.35	31.6%	110	377
Heater	0.28	25.6%	1800	90
Internet Modem	0.92	92.3%	7	1036
Stereo Receiver & Satellite Dish	1	100%	475	102
Water Heater Tank (40 L)	0.58	48.7%	1300	71
Blender	1	95.1%	500	2

The survey also served to gauge the general public's sentiment about the integration of renewable energy sources and smart grid technology currently being tested in Morocco. As long as it does not harm the local fauna and they can afford to help pay for it, 48% of families reported to be enthusiastic about the notion of constructing local green energy parks. On the other side, 1 in 5 households reported to not want to take part in these initiatives because they believe that the government has to provide for them. All families have discussed the environmental consequences of CO_2 emissions and agreed that an update in management procedures is necessary before deploying smart power control. Ten households, however, feel that, as long as they pay their bills on time, they should not be punished for their high electricity usage. Educating the public on the link between residential energy consumption and climate change and economic growth is important.

2.1.3. Energy demand for heating and cooling

Energy demand for heating a conventional residential building in Ifrane is 144 kWh/m²/year, while, for cooling, it is 31 kWh/m²/year [19,40]. The city of Ifrane has been known for its harsh cold climate, and it has recorded the lowest temperatures in Morocco during winters for decades, which makes it the highest in terms of energy demand for heating, and even the lowest, in Morocco, in energy demand for cooling during summers [20,40,41]. Quality of construction is just as important as design when it comes to a building's practical performance. For that, the National Agency for the Development of Renewable Energies and Energy Efficiency has launched thermal construction regulation (TCR) in Morocco [42,43]. The economic benefit of the suggested measures on the back of the ultimate consumer's wallet will determine the feasibility and effectiveness of the implementation of the proposed regulations [44,45]. Following the guidelines of the proposed thermal code for residential buildings should significantly reduce heating and cooling demands compared to baseline conditions [40,45–47], as illustrated in Figure 4. The annual gains from heating and cooling shall then be 116 kWh/m² a year for residential buildings in Ifrane.

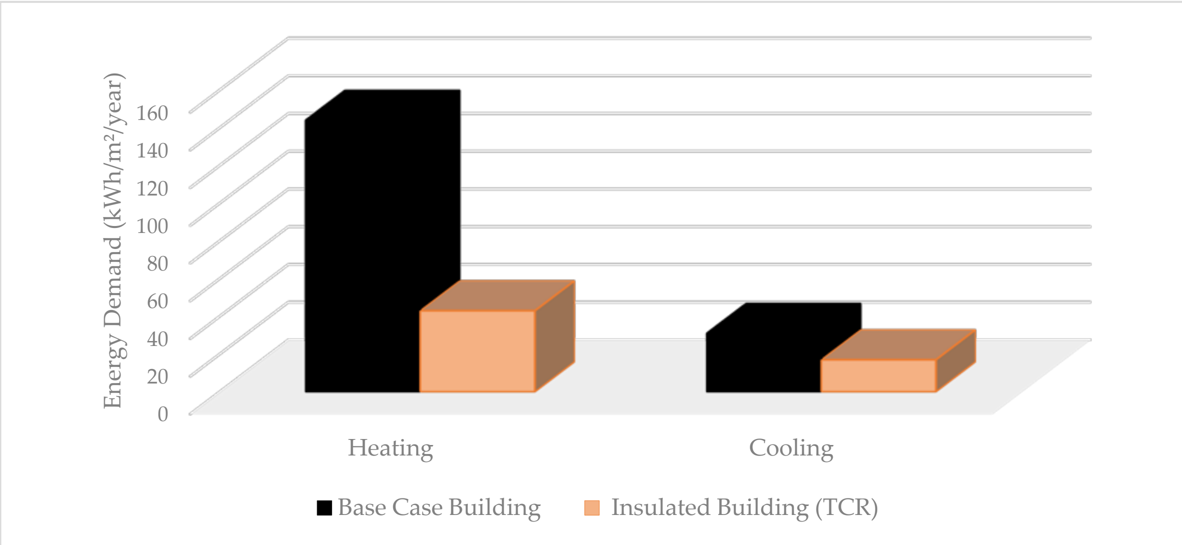

Figure 4. Energy demand comparison in Ifrane between the reference case building and insulated TCR buildings [19,43].

The current buildings in Ifrane are often considered outdated and may not meet modern energy efficiency standards, as noted in some references [43,48]. A significant proportion of the existing homes were constructed before the 1980s. Statistics reveal that 82% of current residential buildings in Ifrane do not meet the TCR in the absence of compulsory adherence to new or old residential buildings [49,50]. Thus, 82% of existing residential buildings are poorly insulated, and up to this date, there are no mandatory renovations or retrofitting programs on residential buildings in Morocco in general, or in Ifrane in particular [51].

2.1.4. Summary and analysis of findings

Electricity consumption in residential buildings is high from 7 to 11 PM and reaches its peak around 9 PM; this is due to various reasons. First, high energy use occurs between 12 and 2 PM and after 6 PM, when people return home from work, school or other activities. Second, residents could take their showers after a long day at work, and, in Ifrane, people use electric water heater tanks. Third, lighting is mostly used during the night. Fourth, various home appliances for cooking, entertainment or phone charging could be used from 12 to 2 PM and late in the evenings. Regarding the used appliances in Ifrane, it could be perceived that the residents use devices with relatively higher nominal wattage than their peers. These devices cost less in terms of their purchasing cost, but could cost many times more in the energy bill; this is because, the higher the nominal wattage, the higher the energy consumption. Indeed, this applies to light bulbs as well, as the ratio of incandescent light bulb use to

LED bulb use is nearly three in Ifrane, and this is due to the low investment cost of the former. The Moroccan Agency for Energy Efficiency has already made a big effort in this regard and has set energy labeling standards for electrical products and appliances that define the energy class of the device [52]; Figure 5 displays an example of an energy class label of a refrigerator. From our study, most of the used home appliances in Ifrane are of energy class B or C, and the lower the energy class, the less efficient is the device. This will lead us to the next important point, which is energy awareness.

Energy awareness is a problem in Ifrane and Morocco as a whole [43,53]. A prospective energy efficiency of 15% in residential buildings can be achieved through energy awareness [43,53]. Ferreira et al. [54] studied smartphone charging habits to identify opportunities for interventions to support better charging behavior, highlighting the implications of overnight charging over battery life and energy use. Karunarathna et al. [55] developed a theoretical model to identify the determinants of behavioral intention to purchase energy-saving appliances in Sri Lankan households and emphasized the need for a comprehensive awareness program addressing environmental aspects and benefits for consumers' health, safety and interests. Waris and Hameed [56] found that consumers' purchase intention of energy-efficient appliances was influenced by their knowledge of eco-labels, environmental concerns, attitudes and perceived consumer effectiveness. The study suggested government policies such as loan schemes, low-interest rates and subsidies to encourage consumers to adopt energy-saving appliances.

Old appliances also contribute to the high electricity consumption in residential buildings in Ifrane, and this is evident from the survey responses. Such behavior is the result of two facts: the consumption behavior of pupils and the low family income in the Fez-Meknes region, as stated by the High Commission for Planning [57].

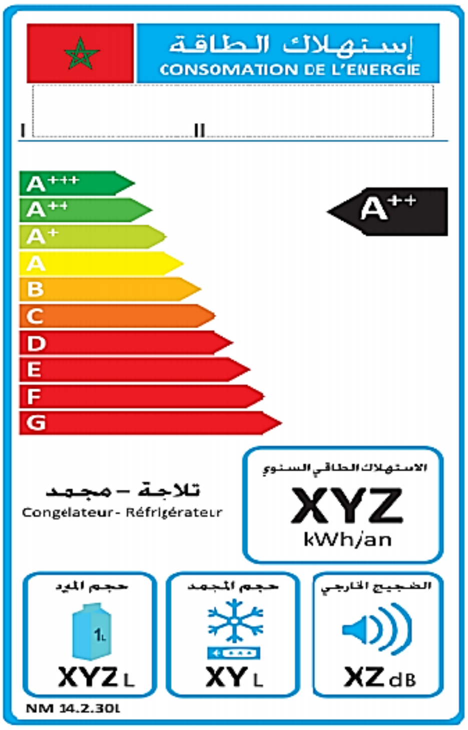

Figure 5. Energy class label in Morocco [52].

The TCR in Morocco is a set of rules governing the thermal efficiency of new and existing structures. This document [43] establishes minimum energy consumption levels for several systems, including systems for heating and cooling, hot water for sanitation, ventilation and lighting. Insulated buildings in Ifrane consume seven times less electricity for heating and twice less for cooling. It is worth mentioning that heating demands exceed cooling demands in Ifrane by 4.65 times, but, except for apartments, most of the residential buildings in Ifrane use biomass and butane for heating and water heating for various reasons. The first reason is the high electricity demand during winter due to the cold climate, and residents might not be able to afford the monthly electricity bill for heating. A second reason is that wood is approximately one-fourth the cost of heating electricity [58] in Morocco, which makes it a pleasing alternative to electricity, in addition to its availability. Nevertheless, this alternative requires more storage space and significant upfront costs, such as transportation and a workforce. The biomass cons will lead us to the second alternative used by the residents in Ifrane, which is butane. This form can quickly heat rooms and consume little; however, it is hazardous and could cause an explosion [59]. Butane is favorable for some families, because it is subsidized in Morocco [60].

In Morocco, the cost and size of biomass heaters can differ, with traditional wood stoves and butane heaters being commonly used for residential heating in Ifrane, according to the Ministry of Energy, Mines, and Environment [61]. The efficiency range of these stoves, as found by Loutia [62] and Krarouch et al. [63], is between 65–85%, and they can deliver up to 22,000 kJ per hour, which is adequate for heating an area of 30 to 75 m^2. Meanwhile, residents of Ifrane use butane heaters with power ranging from 1400 W to 4200 W, consuming between 147 grams to 298 grams of butane gas per hour. Hence, the heating costs can vary between 0.020 and 0.07 USD/kWh for wood stoves, and around 0.04 USD/kWh for butane heaters, which is significantly lower than electric heaters that consume over 0.14 USD/kWh [62].

2.2. Commercial buildings in Ifrane

Along with households, the city’s office buildings, shops, eateries, hotels and schools have all had their energy use analyzed. Commercial buildings represent 24% of the total buildings in Ifrane, among which 12% are businesses and offices, 6% are schools and 6% are hotels. These building types were all gathered under one section, as they share the same conclusions.

2.2.1. Electricity consumption

In the city of Ifrane, commercial buildings have shown an increase in number for the past 14 years [64,65], with a compound increment of 0.7% per year [66]. Plus, over the past quarter of a century, there have been upward trends in both the import and domestic generation of all forms of energy in Ifrane [67–69]. Except for a negligible amount, all of Ifrane's electricity needs are met by power generated on a national scale. The local electricity production is based on solar energy and biomass and is used solely within Al Akhawayn University in Ifrane [70–73]. Indeed, this university is the only producer of electricity in the city of Ifrane; otherwise, electricity needs are all imported from other cities in Morocco through transmission power lines.

Figure 6 displays the total electricity consumption in Ifrane of (S1) businesses and offices from 2014 to 2022, of (S2) commercial buildings from 2014 to 2022 and of (S3) commercial buildings per month in 2022. Data were gathered from Al Akhawayn University Ground & Maintenance

Department and the electricity supplier in Ifrane (ONEE). Data were gathered from January 2014 up to October 2022, and for November and December 2022, they have been forecasted using time-series forecasting in Python. The presented dashboard was generated using HTML5. The dashboard is active and interactive and was used by the authors to ease the analysis and comparison of the figures effectively. As Figure 6 (S1) and (S2) reveal, there was a constant increase in electricity consumption by commercial buildings; however, there was a sudden fall in 2020. This drop was due to COVID-19, and a significant proportion of commercial buildings had to close. Educational buildings adopted online learning; hotels were closed for months for precautionary reasons, while businesses and offices were operating. The latter type was the least affected by COVID-19. Nonetheless, it is worth mentioning that many businesses and offices faced bankruptcy in Morocco in 2020 [74]. Also, due to the spread of COVID-19 among employees or owners, some businesses had to close for weeks, which explains their relatively low electricity consumption in Ifrane. As a matter of fact, it could also be deduced from (S1) and (S2) that, up to this date, hotels are still recovering from the economic crisis due to various factors, such as COVID-19, global inflation and the Russian-Ukrainian War. Yoo [75] spoke of the correlation between electricity consumption and economic growth and worked on South Korea as a case study.

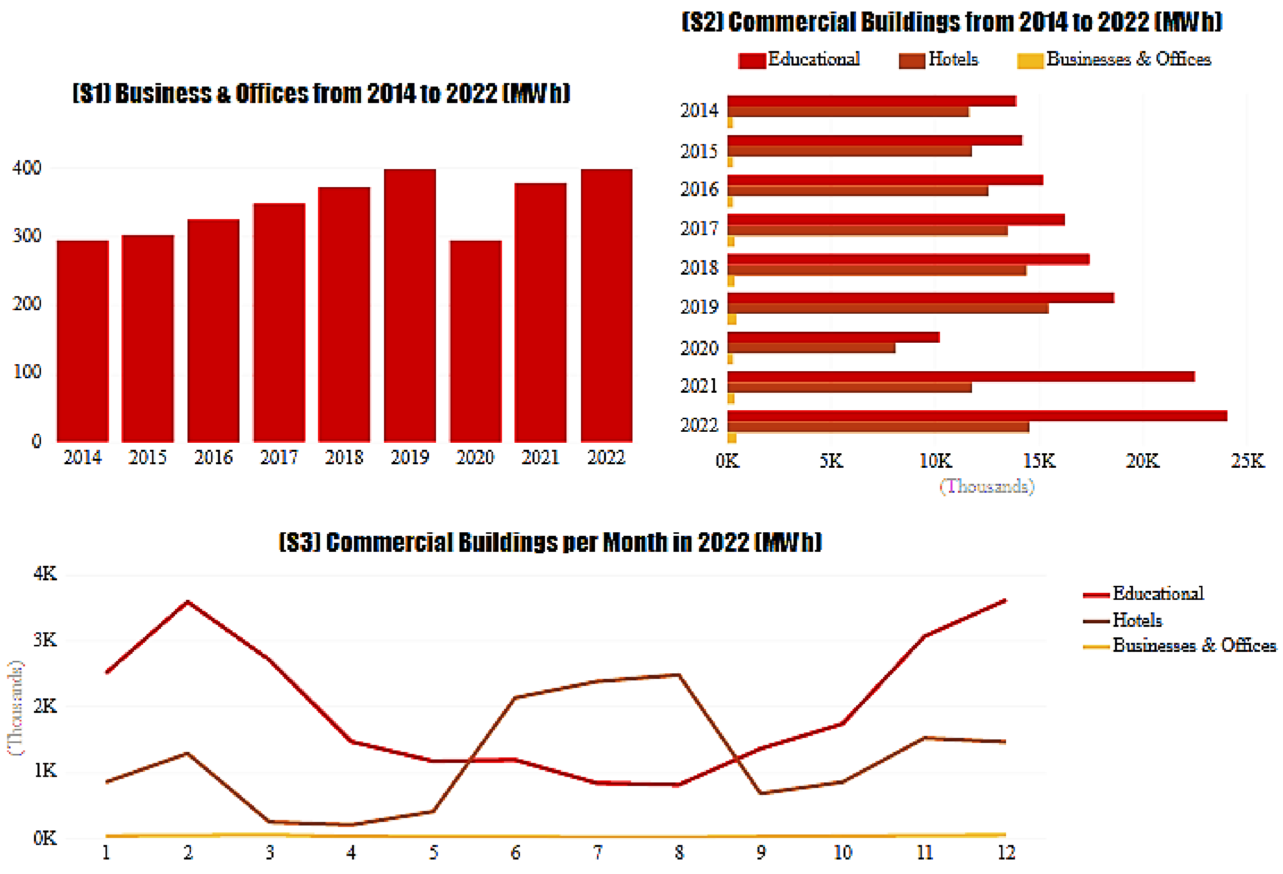

Figure 6. Electricity consumption of commercial buildings in Ifrane.

From Figure 6 (S2) and (S3), educational buildings are the highest in terms of electricity consumption in Ifrane, as Al Akhawayn University alone fosters over 3,400 students with their lodging. Additionally, 30 to 50% of students add intensive summer classes; the others opt for an internship [76]. On the other hand, hotels are more active during summer, thereby consuming more electricity than educational buildings, most of which are on a break during July and August. Concerning the high electricity consumption during winter, it is due to the use of heaters, but this does not apply to small businesses and retailers that close during cold nights and use indoor gas, butane and heaters.

2.2.2. Energy demand for heating and cooling

The energy demand of commercial buildings depends on the building type [16,19,43]. Figure 7 clearly shows the impact of the national TCR on energy demand for heating and cooling. The TCR focuses on the effects of the passive buildings approach on energy economics and energy demand. As it seems from the figure below, educational buildings require more energy for heating and cooling than other building types, which is another reason for the actual electricity consumption in Figure 6, and by adhering to TCR, educational buildings could decrease their electricity demand for heating and cooling to 77% and 36%, respectively.

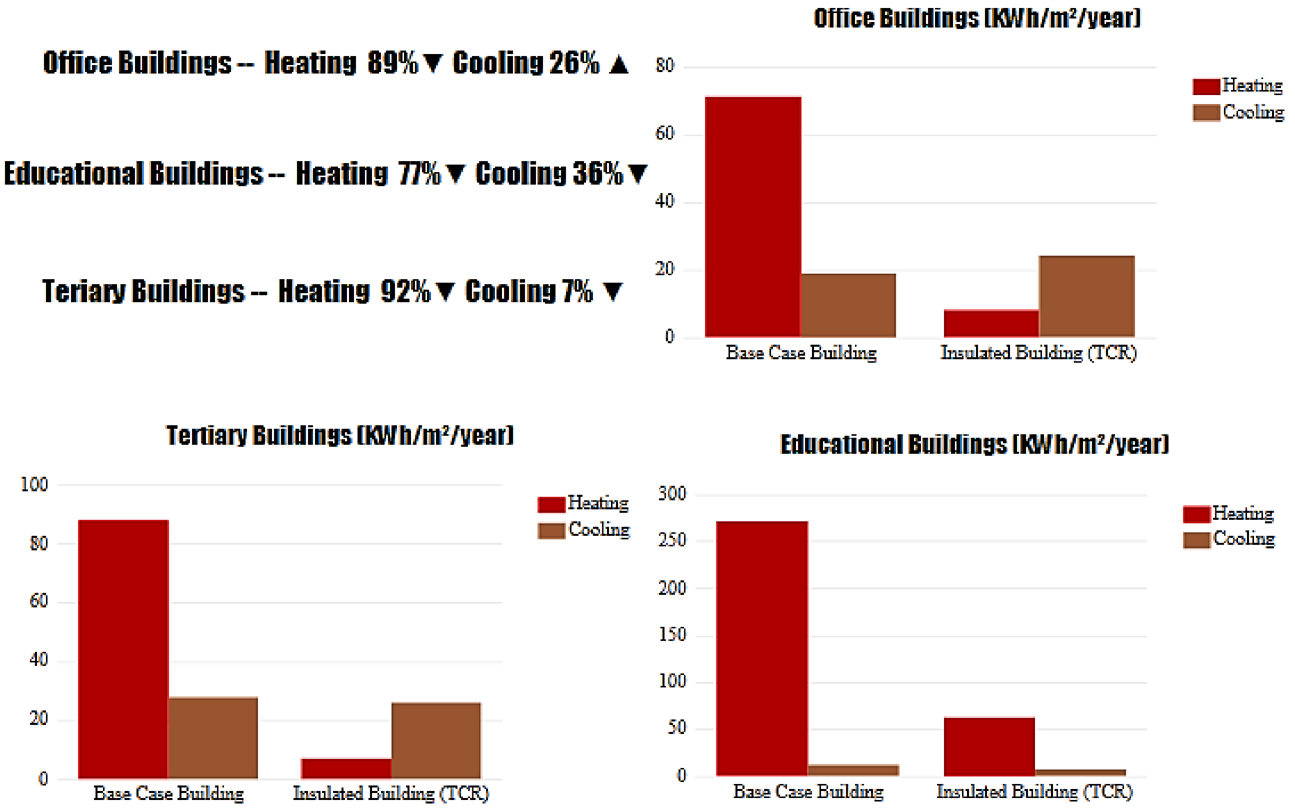

Figure 7. Energy demand for heating and cooling of commercial buildings in Ifrane [43].

The energy used for heating/cooling in Ifrane could be divided into two categories: primary energy (oil and gas) and final energy (electricity). Administrative buildings, educational buildings and tertiary buildings depend heavily on electricity, whereas, small businesses rely on gas. Al Akhawayn

University helps by using photovoltaic panels, oil and biomass to heat its facilities, lower the pressure on the grid and reduce its monthly electricity bills [70–73].

2.2.3. Summary and analysis of findings

Commercial buildings in Ifrane have shown an increase in electricity consumption from 2014 to 2019, but, due to COVID-19, electricity consumption decreased. This drop has been explained to affect the operations, economy and revenue of these commercial buildings. On one hand, educational buildings recovered in 2021, while businesses and offices recuperated in 2022. On the other hand, hotels have been negatively impacted since then, and this was mentioned in the World Bank report [77].

TCR has a big impact on energy demand for heating and cooling for commercial buildings. This might require an additional investment, but the results are promising. The economic profitability in Ifrane is high as compared to other climate zones in Morocco [78–80]. Far from the passive building approach, administrations and offices use conventional HVAC systems, which consume three times more electricity than heat pumps [81–83]. As for educational buildings and hotels, a yearly energy audit is key, as their energy efficiency measures will have the strongest impact on energy savings in the city of Ifrane due to their high electricity consumption as compared to residential buildings, administrations, offices and businesses. The Energy Efficiency of Buildings Law (Law n°47-09) came into effect in Morocco on November 17, 2011, and it regulates the country's energy efficiency policies. The primary goals of the law are to improve energy consumption efficiency, lower the burden of energy expenses on the national economy and promote sustainable development. The law mandates energy audits for households, businesses and other organizations with significant energy use. Companies and organizations involved in the generation, transmission and distribution of energy fall under its scope as well. Consumers, whose annual energy consumption exceeds 1500 toe for businesses in the industrial sector (including energy generators) or 500 toe for businesses in the tertiary sector (including transport businesses), and energy distribution businesses, must undergo an energy audit once every 5 years. The results of these inspections would be compiled by the Moroccan Agency for Energy Efficiency into a database [84,85]. However, a yearly energy audit and further energy efficiency measures are needed for educational buildings and hotels in the city of Ifrane.

3. Improving energy efficiency in buildings

Improving energy efficiency implicitly leads to pollution reduction, less energy production, less grid dependence and a better energy economy. All subsystems must be precisely described if a reasonable level of energy efficiency is to be achieved using the options available. Policy development, evaluation, monitoring and energy efficiency improvement are the factors that should be within the decision-maker’s control. The anticipated outcomes are a decrease in environmental pollutants, reduced energy production and usage cost savings. Emissions of greenhouse gases rise as a result of rising energy consumption. A building's energy efficiency can be increased due to a variety of variables: (1) energy-saving awareness, (2) use of a sustainable and economical building envelope, (3) use of energy-efficient devices, (4) renewable energies integration and (5) policies and governance.

3.1. Energy-saving awareness

Societal stability and economic growth depend on widespread energy conservation knowledge, which includes technical expertise, individual behavior, population propensity and attitudes toward sustainable societies [86,87]. Accurate data on public awareness levels can benefit decision-makers, environmentalists, educators and businesspeople in establishing social and economic policies that support sustainable development [88].

A survey of 58 residential buildings, five educational institutions, 28 offices and businesses and three hotels in Ifrane shows that residents lack knowledge about wise energy behaviors (Table 2). Managers of educational buildings have difficulty convincing users and students to power off appliances when not in use, while this action is widely accepted in other types of buildings. All hotel respondents supported the idea of energy-saving activities, but not all have implemented yearly energy audit programs. Additionally, not enough residents or industries in Ifrane are aware of the national TCR. The maintenance of heaters can help to lower energy consumption, monthly energy bills and environmental pressures, including reducing excessive wood-cutting in the region. Ongoing public campaigns for energy conservation are necessary.

Table 2. Energy-saving behavior in the city of Ifrane.

Building type	Power off appliances when not in use	Yearly energy audit	Awareness of TCR	Maintenance of heaters
Residential Buildings	86% Yes 10% No		22% Yes 67% No	31% Yes 53% No
Educational Buildings	20% Yes 80% No	60% Yes 40% No	40% Yes 60% No	100% Yes 0% No
Offices and Businesses	100% Yes 0% No	0% Yes 100% No	18% Yes 78% No	79% Yes 19% No
Hotels	100% Yes 0% No	67% Yes 33% No	100% Yes 0% No	100% Yes 0% No

The survey's responses revealed opportunities and challenges for enhancing Morocco’s efficient energy use. Respondents were divided into groups whose priorities varied according to the difficulties they faced. For instance, while many schools and universities supported the idea of energy-rating labels for consumer electronics, many locals believed that phasing out tungsten lamps was a more efficient strategy for cutting energy consumption. "I don't know the right methods and technologies," "lack of servicing providers" and "insufficient information" all topped the list of common complaints. However, these concerns can be mitigated through increased investment in education and state backing for businesses providing technical assistance. The results of this poll suggest that the municipality of Ifrane could take some positive steps to further encourage people to reduce their energy consumption.

3.2. Sustainable and economical building envelopes

Existing buildings in Morocco may not meet modern energy efficiency standards [41,48], and retrofitting them can have numerous benefits, such as cost savings, improved indoor climate and user comfort, reduced air pollution and increased property value [89–91]. To make energy-efficient building renovation cost-effective, the cost-effectiveness of energy-saving solutions must be considered in rehabilitation planning [92]. Morocco could benefit from European urban energy modeling and the certification of building energy performance to monitor and improve energy efficiency and reduce greenhouse gas emissions [35]. For new building construction projects, factors such as the thickness of the thermal insulation material, glazing and insulation impact energy use and the financial outlay [93–96]. Funding for sustainable construction can come from tax revenue, subsidies and lowering the VAT on sustainable construction materials, as well as encouraging research on innovative building retrofitting [41,48].

3.3. Energy-efficient devices

Despite measures by the Moroccan government to improve energy conservation, energy-efficient technology and appliances are not widely adopted, even when financially beneficial. This is known as the "energy efficiency gap" or "energy dilemma," and it has been a topic of research and policy for several decades [97–100]. Factors contributing to this gap include imperfect information, misplaced incentives, consumers' failure to consider future energy savings, biased beliefs about energy consumption and prices and heuristic decision-making [101–103]. Sociodemographic factors, such as gender, education, income and age, also influence consumers' purchase decisions [104]. Attitudinal qualities, such as concern for the environment, may also affect the adoption of energy-efficient appliances, but research in this area is limited [103].

Fewer studies have evaluated the impact of energy labels on customer choices about household appliances, despite their increasing prevalence worldwide. Banerjee and Solomon [105] evaluated Green Seal, Scientific Certification Systems, Energy Guide, Energy Star and Green-e. Government programs, like Energy Star, were more successful than private ones. Private schemes barely affect the market for appliance energy labeling. Sammer and Wüstenhagen [106] conducted a preference survey with retail customers. According to their study, Swiss consumers value A-rated washing machines 30% more than C-rated ones.

Research is needed in Morocco on energy-efficient devices, as there are none besides heating and cooling alternatives. Furthermore, there is a lack of studies on consumers' behaviors and the impact of energy labels on customer choices in Morocco. The educational system in Morocco, particularly in the city of Ifrane, should incorporate energy-efficient behavior, and technological devices and appliances that do not meet government standards should be banned. Home energy management systems could be integrated to allow users to monitor their electricity consumption and environmental impact. This solution connects with the smart grid and smart house, making dynamic decisions for intelligent and efficient energy management. Assessment and monitoring are crucial.

3.4. Integration of renewable energy systems

Countries are considering incorporating renewable energy systems in buildings for zero-energy balance. Shen and Sun [107] evaluated two design strategies for a cluster of net-zero energy buildings in Hong Kong. They used a water-cooled chiller system, solar power and wind energy. The initial expenses for HVAC, photovoltaics and wind turbines were lowered by 14.4%, 13.7% and 11.8%, respectively. Good et al. [108] compared solar thermal energy, solar photovoltaic energy and solar photovoltaic energy combined with thermal energy storage for a zero-energy home in Norway.

Buildings using high-efficiency photovoltaic modules were closest to a zero energy balance, whereas photovoltaic/thermal systems produced more energy than solar thermal energy collectors.

Common renewable energy systems in buildings include photovoltaic, small wind power and hybrid photovoltaic/wind systems for electricity generation, solar thermal energy collectors for domestic hot water production, solar cooling systems and solar ovens for cooking. High-energy performance buildings require an evaluation of a large variety of design ideas to fulfill specific economic or environmental goals [109]. To find optimal solutions, various researchers [23,110,111] have used single- or multi-objective optimization. Optimization involves selecting the best solution from a set and finding the maximum or minimum of a function or multi-functions.

Choosing the right renewable energy technology for sustainable buildings is crucial, and cost is a significant factor. The levelized cost of energy, which represents the lifetime cost of a project per unit of energy produced, is commonly used for comparison. Solar photovoltaic energy still cannot compete with grid electricity in Morocco, as shown in Tables 3 and 4, which display the electricity prices for residential [112] and commercial buildings [113], respectively, according to the national electrical contractor. While complying with TCRs, buildings can achieve a higher annual solar fraction due to proper insulation, glazing, enthalpy and orientation. Abdou et al. [114] also found that Ifrane has the highest annual domestic heat water energy demand in Morocco, at 41.06 kWh/m², due to its cold climate. The solar fraction is the most critical metric for evaluating the efficiency of a collective solar domestic water system in a region [115], and it is the proportion of the annual hot water load that can be satisfied by solar energy [116].

Table 3. Prices of electricity for residential buildings in Ifrane [112].

Consumption per month	Price (USD/kWh)
0 to 100 kWh	0.09
101 to 200 kWh	0.11
201 to 300 kWh	0.12
301 to 500 kWh	0.14
≥ 501 kWh	0.16

Table 4. Prices of electricity for commercial buildings in Ifrane [113].

Period type	Period hours	Price (USD/kWh)
Winter		
Peak	5 p.m. to 10 p.m.	0.14
Middle Peak	7 a.m. to 5 p.m.	0.10
Off Peak	10 p.m. to 7 a.m.	0.07
Summer		
Peak	6 p.m. to 11 p.m.	0.14
Middle Peak	7 a.m. to 6 p.m.	0.10
Off Peak	11 p.m. to 7 a.m.	0.07

3.5. Policies and governance

Replacing technology with energy-efficient devices may not guarantee energy savings because of consumer behavior, measurement standards, definitions and the rebound effect. Policies aimed at energy efficiency may result in higher energy usage, and energy labels may reward larger equipment instead of smaller ones. This may lead consumers to purchase more massive and powerful appliances or structures, increasing their energy usage. Therefore, it cannot be assumed that implementing energy efficiency rules will necessarily result in decreased energy use [117–119].

Adjusting energy consumption levels can reduce energy usage without requiring investment in new technology. Energy sufficiency, an alternative to energy conservation, has been included in policymaking [120]. Herring [119] proposed sufficiency policies focused on "living well on less," while Sachs [121] emphasized the importance of "doing the right things". Scholars have explored the concept of energy sufficiency and its implementation in policymaking [122]. This approach involves tolerating lower levels of comfort and compromising living standards by reducing internal space or building size. According to Spangenberg and Lorek [123], living space per person counteracts building sefficiency benefits, and policy instruments should regulate construction size for sufficiency and efficiency. The promotion of voluntary sufficiency is recommended due to its impact on individual liberty and societal justice [124], and it should be integrated into a broader welfare and social justice paradigm.

Environmental authorities in Ifrane prioritize negotiation, consensus building and voluntary measures as the legislation lacks explicit inspection and enforcement capabilities. Enforcement of the thermal regulation remains difficult, with not all newly built structures following the code, and building permits issued by local authorities do not include inspections. Although the Moroccan Agency for Energy Efficiency is required to perform random audits, they are not comprehensive. The Ministry of the Interior is revising the standards for urban buildings to include more stringent monitoring, control and enforcement procedures, but new measures established in 2015 only apply to new buildings. Training for architects and construction workers is also planned. However, systematic implementation of these regulations is lacking, and minimum energy performance criteria for appliances and retrofitting existing buildings are not priorities. Targeted inspections, building certification and training are needed to increase the enforcement of thermal regulations [125].

The potential rise in overall building cost is an important factor in the motivation to not enforce Law 47-09 in residential buildings. Construction investors have a contract with the government to build social housing and cannot charge more than a set real estate price per square meter. Seven demonstration projects showcasing energy efficiency and renewable energy utilization in residential and commercial buildings had been implemented by the end of 2017 across a range of climate zones in Morocco, but not in Ifrane. They estimate a 5–7% rise in building costs due to the new thermal regulation; however, they expect this to decrease as more companies gain expertise on the new standards [125]. The government determined that imposing thermal control can raise living costs. While this would only modestly increase commercial building costs, which may be passed on to businesses, the affordability of social housing may affect vulnerable citizens. The government should lead on social housing renovation/construction and adapt its allowable assistance levels.

Palermo et al. [126] analyzed policies adopted by local authorities under the Covenant of Mayors, using 315 Monitoring Emissions Inventories; they found that municipal assets and structures were the most commonly covered policies. Kona et al. [127] suggest that local authorities can utilize various modes of urban climate governance to facilitate and mobilize investments in local energy generation, which would lead to improved climate action efforts. Morocco could benefit from applying the concept of the Covenant of Mayors by involving local authorities in decision-making and vision-sharing according to local resources and potential [128].

4. Discussion

4.1. Findings and their application in Morocco

Energy consumption in Ifrane has been rising quickly along with the city's rapid economic expansion and rising prosperity in recent years; based on the past data of electricity consumption from 2013 to 2022, it is anticipated that electricity consumption in buildings will increase to 45 GWh in 2030 from 42 GWh in 2022, and commercial buildings will represent 91% of the total electricity consumption of buildings in the city of Ifrane. Thus, an emphasis on commercial buildings' energy efficiency is mandatory and would have a crucial effect on the electricity consumption and environmental impact in Ifrane.

Ifrane has lately implemented efforts to increase energy efficiency in response to this increased demand and has made some headway toward the objective of creating a sustainable, energy-efficient city. The Moroccan government has developed a TCR that aims to improve energy efficiency in buildings by setting minimum requirements for insulation, ventilation and heating and cooling systems. The Moroccan Agency for Energy Efficiency has also enacted energy labeling standards to define the energy class of appliances. The kingdom has been enacting public campaigns for energy awareness on national TV channels since 2008. On the other hand, the municipality of Ifrane has set directives to assist citizens, businesses and public administration in increasing their energy efficiency. However, there are still no fundamental energy-saving legislative policies or regulations in the city of Ifrane or any other local region in Morocco; hence, up to this date, the legislated policies have only displayed success in energy-intensive hotels and industries, but could not succeed with residential buildings and small businesses. Morocco must follow suit for residential buildings and small businesses by enacting legislation with the same goal of promoting energy conservation and enhancing energy efficiency in a way that is suited to the region's economy, topography and climate.

Publicity campaigns that promote energy efficiency can raise people's awareness of the energy problem and climate change while also equipping them with the knowledge and skills they need to act responsibly. From the survey results, it seems that the municipality of Ifrane has to develop educational programs and organized community activities in this regard.

The key to achieving energy sustainability in the city of Ifrane is to make efficient use of energy in buildings. Buildings that are more efficient at using energy should be erected, and systems for managing energy consumption should be standardized. The energy efficiency of buildings should be monitored and systematically surveyed on a regular basis. Energy efficiency in buildings could be attained by implementing sustainable building construction, taking the national TCR as a reference, retrofitting buildings and the wise investment in energy-efficient appliances and technologies. In this regard, the Moroccan government and municipalities should promote the reading of energy labels on technologies, electrical instruments and home appliances.

Given Morocco's lack of indigenous fossil energy resources means that the city must look toward renewable energy, particularly solar, to ease the burden of energy shortages and achieve the objective of becoming a more energy-efficient metropolis. However, without government assistance, this will not materialize. Alternatives to solar electricity should be explored in addition to expanding solar usage. It is possible to harness and develop wind energy in universities' and laboratories' research programs.

The government is the legislative and executive institution in Morocco and should consider revising current energy labels' policies to avoid higher energy use, promote energy sufficiency, enforce

TCRs and schedule yearly energy audits for commercial buildings. Furthermore, the government can economically incentivize businesses or municipalities to adopt energy, material and community resource efficiency measures. Last but not least, the government should consider engaging, monitoring and assessing local authorities in the implementation of energy regulations, as is the case in Europe under the Covenant of Mayors.

4.2. Comparison of findings to other Cfa cities

Cities under a similar climate type and economy were compared to Ifrane with regard to energy use, efficiency and policies; such a comparison would help us to evaluate the energy efficiency status in Morocco. As illustrated by Köppen [129] and Chen and Chen [130], Ifrane belongs to the Cfa climate zone (Figure 8), categorized by hot and humid summers and cool winters. Under the same climate zone, Perez-Garcia et al. [131] examined the constructional features of 588 multi-story listed buildings (around 6000 dwellings) in Spain. The study found that energy consumption for residential buildings in Gerona was 133 kWh/m², while space heating accounted for 72 kWh/m². These results highlighted the buildings' poor thermal performance and suggested that there is significant potential for energy savings and CO_2 emission reduction, especially when considering the current requirements set by the Spanish building code and appliances' eco-labeling standards. In addition, Figure 9 illustrates the outcomes of an end-use analysis conducted by Perez-Garcia et al. [131] on the typical yearly energy usage of 8.96 MWh in residential buildings.

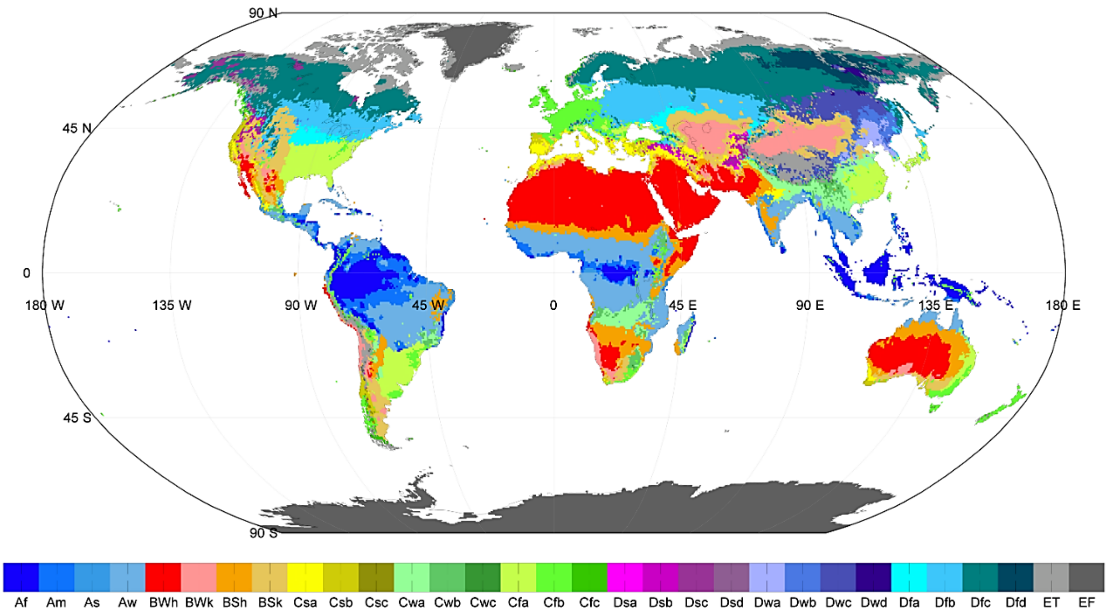

Figure 8. Climate classification map [130].

Wang et al. [132], Cao et al. [133] and Deng et al. [134] assessed energy consumption in residential and commercial buildings in Cfa climate zones in China. According to Wang et al. [132], the average efficiency of household space heating was 0.69. This means that households in those Cfa regions could potentially lower their electricity consumption for heating by 31% without compromising the current level of indoor thermal comfort during winter. The potential for space heating savings is heavily influenced by the building code and standards. Cao et al. [133] discussed the control of energy use intensity implemented by the Chinese government and provided cost-effective solutions to fully implement the quota in China. Using a bottom-up approach, Cao et al. [133] demonstrated that heating and cooling in Cfa climate zones in China require 8.32 kWh/m², which makes up 32% of the total energy demand of residential buildings. In the same fashion, Liu and Kojima [135] computed the typical energy consumption of residential buildings in Cfa climate zones in China to be 2.64 MWh per year. On the other hand, in their study, Deng et al. [134] analyzed the energy usage in educational buildings and conducted a questionnaire survey to investigate the usage of appliances and air conditioners in classrooms and dormitories. The findings indicated that 74.8% of electricity consumption was attributed to human behavior. Specifically, male students tended to consume more electricity due to their increased use of computers. Additionally, lower floors were found to be more energy-intensive, likely due to poorer environmental conditions. Furthermore, rooms facing south consumed more electricity during summer, whereas those facing north consumed more during winter. Ultimately, Figures 9 and 10 presents the summarized comparative energy consumption findings of China and other cities of similar climate zone discussed in the text.

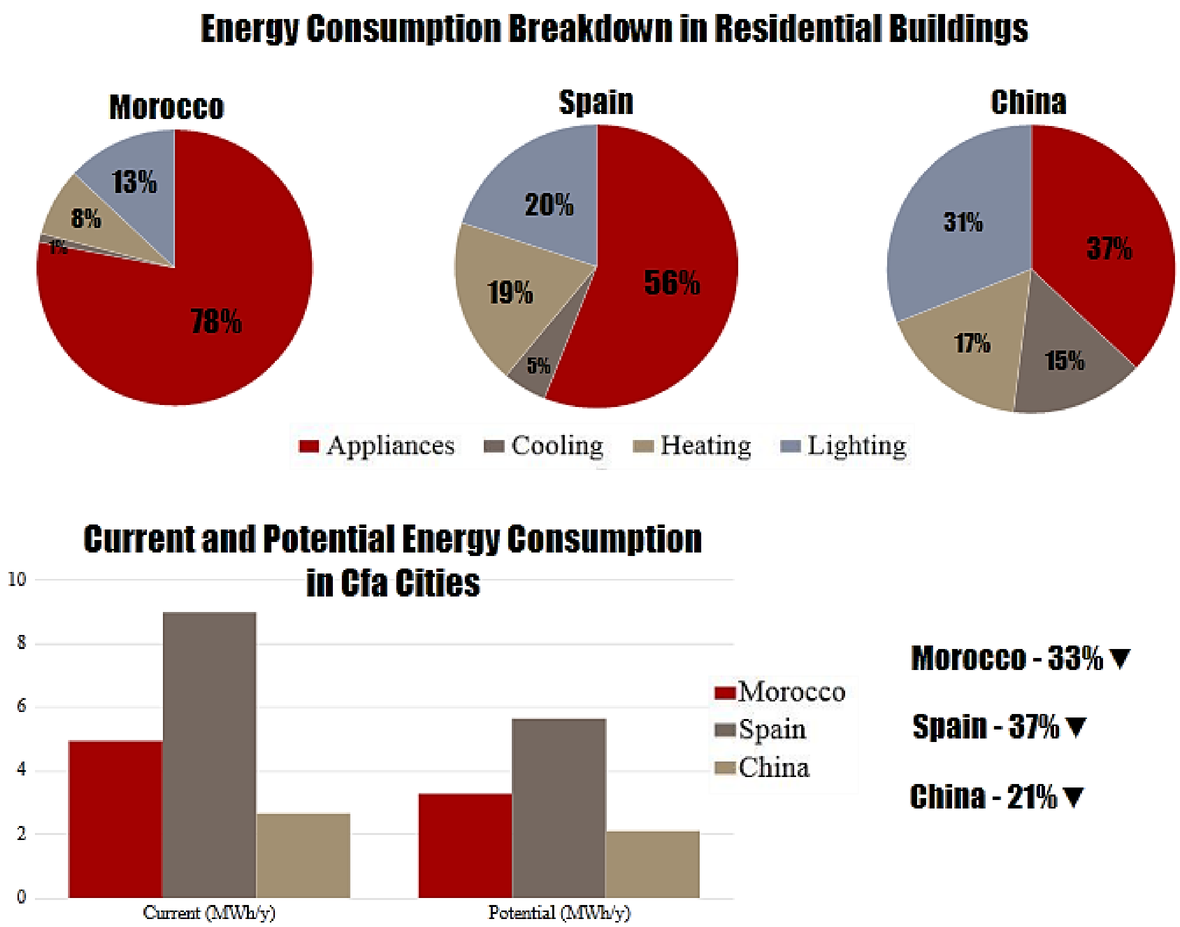

Figure 9. Energy consumption data of residential buildings in Cfa climate zones [131–133].

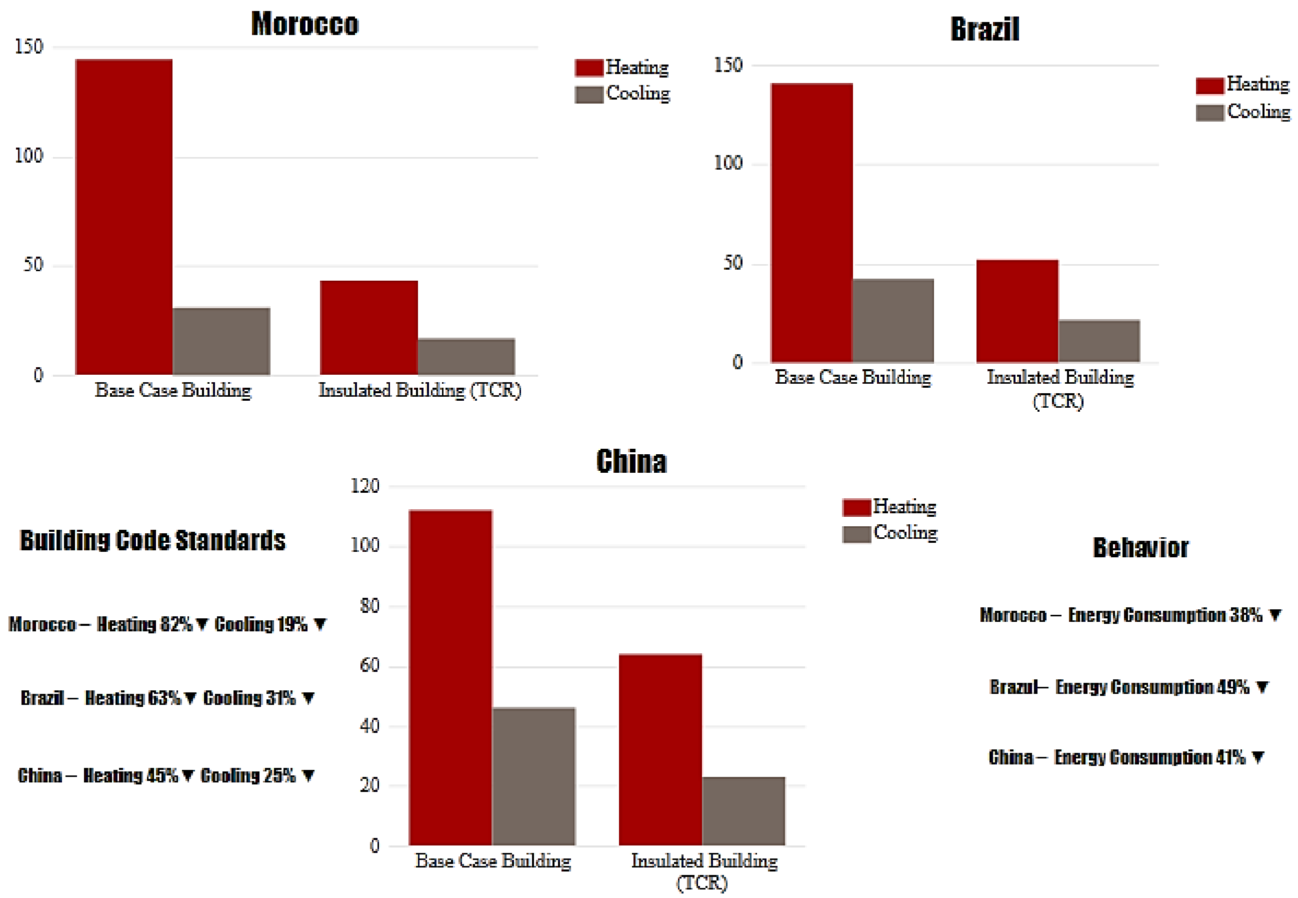

Figure 10. Energy consumption data of commercial buildings in Cfa climate zones [134–136].

In their groundbreaking study, Geraldi et al. [136] conducted a top-down examination of Brazil's non-residential building stock, which encompasses Cfa climate zones. The study's key metrics comprised the floor area, energy use intensity and operation patterns, while also identifying the prevalent wall constructions, lighting systems, equipment, water heating and HVAC systems for each typology. To investigate the relationship between energy use intensity and building characteristics, the authors conducted a complementary statistical analysis, which included ANOVA and regression tests, to determine the influence of energy usage indicators on the energy use intensity of each building typology in Brazil. The paper revealed an opportunity to reduce energy consumption in non-residential buildings in Brazil through building retrofitting and energy awareness. A comparative energy consumption of Brazil is displayed in Figure 10.

According to Figure 9, residential buildings in Cfa climate zones consume most of their electricity through appliances. In Ifrane, a typical residential building uses an average of 4.92 MWh per year, while, in Cfa cities in Spain and China, the average annual electricity usages were reported to be 8.96 [131] and 2.64 MWh [133], respectively. Unlike Morocco, where residents heavily rely on biomass or conventional butane heaters, citizens in Spain and China use heat pumps, electric heaters and air conditioners, which explains the higher electricity consumption for heating in Spain and China. Furthermore, Moroccans are accustomed to high ambient temperatures [137], resulting in lower usage of air conditioners compared to Spain and China. Morocco, Spain and China all face issues with poor energy behavior and inefficient appliances and lighting that affect their overall energy efficiency, but Morocco and Spain require more energy sufficiency.

The findings presented in Figure 10 underscore the crucial role of building code standards and energy behavior in decreasing the energy demands of heating and cooling systems, as well as the overall energy consumption in commercial buildings situated in Cfa climate zones. The data show that implementing effective building code standards and energy-saving practices can significantly reduce energy consumption levels in commercial buildings, thereby helping to mitigate climate change impacts. China stands out as a leader in this area, having made notable progress in reinforcing building code standards for non-residential buildings. In contrast, Morocco and Brazil still lag behind in this regard. The lack of effective building codes in these countries leads to energy inefficiencies, higher energy costs and negative environmental impacts. Furthermore, energy behavior and efficiency need to be emphasized and promoted in all three countries, as they are still in their early stages of adoption. Commercial building occupants and operators should be educated on energy-saving measures and encouraged to adopt them, such as utilizing energy-efficient lighting, heating and cooling systems, as well as optimizing building occupancy schedules. Overall, the results of Figure 10 highlight the importance of adopting effective building codes and promoting energy efficiency in commercial buildings, as these actions are crucial to achieving sustainable development goals and mitigating the adverse effects of climate change.

5. Conclusions

Unsustainable energy consumption patterns have far-reaching consequences for ecosystems and climate change, as well as for human health and quality of life. However, cities that are sustainable and energy-efficient can reduce environmental degradation and catalyze social and economic development, equity and resilience. Being the city with the highest energy demand in Morocco, an assessment of the city of Ifrane would translate into national efforts to reduce energy consumption and promote efficiency. As the first systematic evaluation of Morocco's efforts to promote the construction of a sustainable energy-efficient metropolis, this study has offered a comprehensive picture of building energy usage in Ifrane.

With the use of the collected data and surveys, this article detailed the energy consumption of residential and commercial buildings in Ifrane. This paper also discusses the most prominent initiatives in Morocco to make building energy use more efficient and provides a comprehensive literature analysis on the topic of the viability and applicability of energy efficiency and renewable energy technologies for both new and existing buildings in Ifrane. This paper outlines a literature review to show that the potential for improved energy efficiency is still substantially untapped. According to the stated investigation, increasing the energy efficiency of both homes and businesses could have large and varied effects. The analysis assessment uncovered a roadmap for cutting down on building energy use and its detrimental effects on the environment. This roadmap can serve as a guide for boosting Ifrane's energy consumption in buildings and include (i) the importance of energy awareness and behavior, (ii) the need for economical and sustainable construction materials, (iii) the promotion of energy performing devices and appliances, (iv) the integration of renewable energies for on-site clean energy generation and (v) the adoption and enforcement of comprehensive energy efficiency regulations. To improve the energy efficiency of buildings in Ifrane, researchers and policymakers can use the detailed recommendations provided by this roadmap. Due to the similarities in the characteristics of structures, the majority of the stated guidelines apply to countries in Cfa climate zones.

Compliance with ethical standards

All subjects participated voluntarily and received a small compensation. The study was performed in accordance with the ethical standards of Helsinki and does not require prior approval, according to the Moroccan research code. Also, the authors used Grammarly to write mistake-free paragraphs and ChatGPT to improve writing style.

Acknowledgment

This work was supported by the National Center for Scientific and Technical Research (CNRST), within the framework of '*Development of Smart Metering and Energy Management System in Morocco*'.

Conflict of interests

The authors know of no conflicts of interest associated with this publication, and there has been no significant financial support that could have influenced the outcome.

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