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Energy Analysis of the Faculty of Technology Using RETScreen

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Abstract

This study presents an energy audit of the Faculty of Technology at the University of Tlemcen to evaluate its energy performance and identify cost-effective efficiency measures. Electricity and natural gas consumption data from 2022–2024 were analyzed using regression modeling and RETScreen software. Results showed that heating accounts for over 90% of total energy use, with significant losses from poor insulation, infiltration, and inefficient controls. Six Energy Conservation Measures were proposed, achieving potential savings of 25% in energy use and notable reductions in energy losses. The findings demonstrate that targeted retrofits, even under subsidized tariffs, can deliver substantial technical, financial, and environmental benefits.

Key words: Energy audit, Energy efficiency, RETScreen, Energy conservation measures, University buildings

Résumé

Cette étude présente un audit énergétique réalisé au sein de la Faculté de Technologie de l'Université de Tlemcen, visant à évaluer sa performance énergétique et à identifier des mesures d'efficacité rentables. Les données de consommation d'électricité et de gaz naturel pour la période 2022–2024 ont été analysées à l'aide d'une modélisation par régression et du logiciel RETScreen. Les résultats montrent que le chauffage représente plus de 90 % de la consommation totale d'énergie, avec des pertes importantes dues à une isolation insuffisante, à des infiltrations d'air et à des systèmes de contrôle inefficaces. Six mesures de conservation de l'énergie ont été proposées, permettant des économies potentielles d'environ 25 % de la consommation et une réduction notable des pertes énergétiques. Les conclusions de l'étude démontrent que des interventions ciblées, même dans un contexte de tarifs subventionnés, peuvent offrir des avantages techniques, économiques et environnementaux significatifs.

Mots-clés: Audit énergétique, Efficacité énergétique, RETScreen, Mesures de conservation de l'énergie, Bâtiments universitaires.

ملخص

تقدّم هذه الدراسة تدقيقاً طاقوياً لكلية التكنولوجيا بجامعة تلمسان بهدف تقييم أدائها الطاقوي وتحديد الإجراءات الفعّالة من حيث التكلفة لتحسين الكفاءة. تم تحليل بيانات استهلاك الكهرباء والغاز الطبيعي للفترة من 2022 إلى 2024 باستخدام النمذجة الإحصائية وبرنامج RETScreen. أظهرت النتائج أن التدفئة تمثل أكثر من 90% من إجمالي استهلاك الطاقة، مع خسائر كبيرة ناجمة عن ضعف العزل وتسرب الهواء وأنظمة التحكم غير الفعّالة. تم اقتراح ستّ إجراءات للحفاظ على الطاقة، تحقق وقرأً يقدر بحوالي 25% من الاستهلاك وتقليلاً ملموساً في الفاقد الطاقوي. وتُظهر نتائج الدراسة أن التدخّلات المستهدفة، حتى في ظل نظام التعريفات المدعومة، يمكن أن توفر فوائد تقنية واقتصادية وبيئية كبيرة.

الكلمات المفتاحية: تدقيق الطاقة – كفاءة الطاقة – برنامج RETScreen – إجراءات الحفاظ على الطاقة – المباني الجامعية

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GENERAL INTRODUCTION

General Introduction

Energy demand in the building sector has increased significantly in recent years and remains one of the highest energy-consuming sectors. Globally, the primary energy consumed by buildings accounts for approximately 40% [1]. Awareness of environmental, economic, and social risks has prompted political and scientific leaders to take a series of initiatives to improve building performance.

Humans increasingly rely on high-energy-value resources that are non-renewable and polluting. This has led to fears of a premature depletion of these resources, “the consumption of all the generations that have lived on Earth has been surpassed by the consumption of natural resources over the past 40 years” [2]. This alarming trend has reinforced the urgent need to integrate energy efficiency into all sectors, particularly buildings, which are among the most energy intensive.

The global push toward sustainable energy use emphasizes the need not only for technological upgrades but also for behavioral change and institutional commitment, it is a matter of strategy, awareness, and shared responsibility. Whether driven by policy, economic constraints, or environmental ethics, all stakeholders from engineers and facility managers to policymakers and everyday users must engage in responsible energy use. Raising public awareness and fostering a culture of energy consciousness are critical to creating lasting behavioral and operational change, one of the most effective strategies for addressing inefficiencies in energy consumption is the implementation of energy audits, which systematically assess energy flows within a building or facility. In Algeria, however, energy auditing is still underutilized, especially in the educational sector, where consumption levels are high but often poorly monitored or managed [3].

All around the world, and especially in Algeria, energy management is essential. In a context where demand is constantly increasing in our society, and focusing on the current issue in our country regarding energy loss (such as insulation problems), we must conduct an energy audit. The energy audit involves a process of verifying energy use and, upstream,

identifying areas where thermal loss can be minimized if not completely eliminated. This audit includes several tasks that can be carried out depending on the type of inspection and the function of the facility being studied. The study begins with an examination of historical data on energy consumption, which can be compiled from electricity and/or gas bills.

In short, the audit aims to determine where, when, why, and how energy is being used. This information can then be used to identify opportunities to improve energy efficiency, reduce energy costs, and lower greenhouse gas emissions that contribute to climate change. Energy audits can also assess the effectiveness of energy management opportunities (EMOs) once they have been implemented. Although energy audits are often carried out by external consultants, much can be done using internal resources. We will present a practical method for conducting energy audits in various structures so that even small businesses can integrate auditing into their overall energy management strategies. The energy audit involves assessing the energy performance of a facility and providing a diagnosis in the form of recommendations to improve the building's energy efficiency. This report includes the following elements:

- Information on the energy performance of the structure
- Improvement proposals with achievable savings
- Technical data sheets on the proposed recommendations
- Contacts, publications, and financial incentives

The auditor's role is to provide advice based on the energy assessment, the needs, and the budget. First of all, the boundaries of a system must be defined. This includes any building, any area within a building, any operating system, any equipment that consumes energy, or any set of individual installations. Around these elements, a figurative boundary can be drawn, as shown in a schematic diagram (Figure 1). [4]

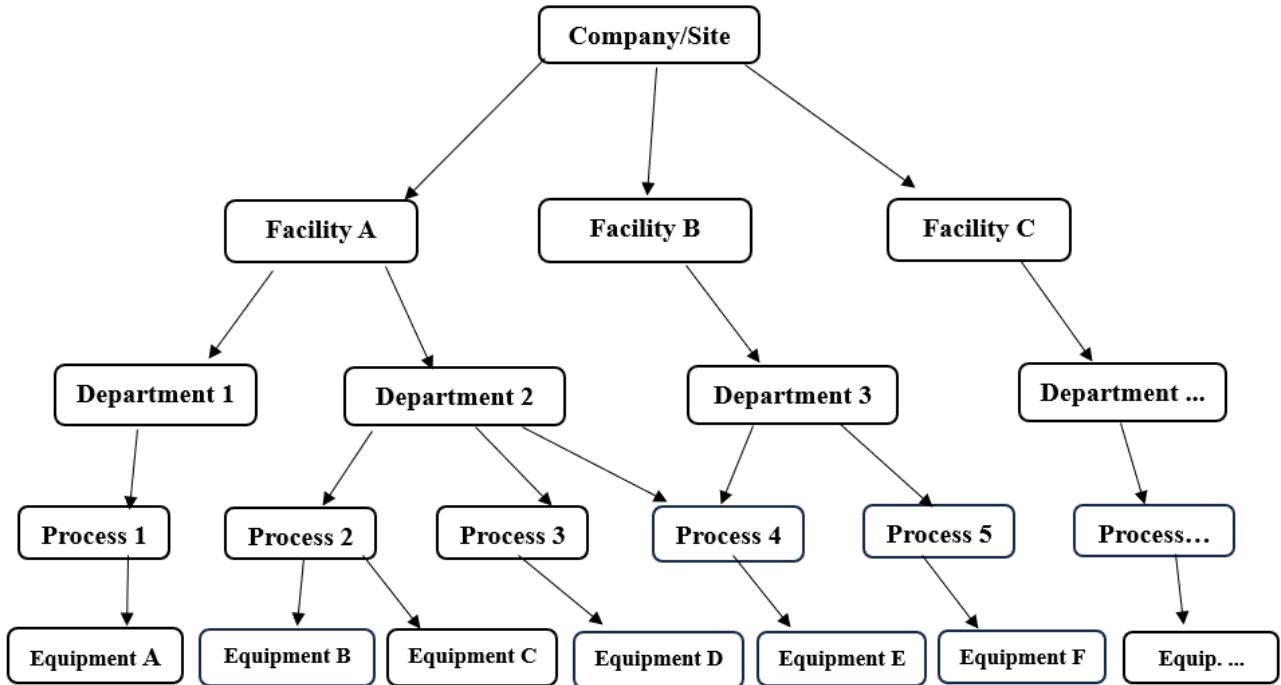


Figure 1.Structure of an energy consuming system

The second challenge is technically more difficult because it involves collecting data on energy flows from various sources through direct measurements. It also likely requires estimating energy flows that cannot be measured directly, such as heat loss through a wall. Since the only energy flows of concern are those that cross the system boundaries, the following should be taken into account when measuring energy flows:

- Select practical measurement units that can be converted into a single unit for data consolidation.
- Be able to calculate the energy contained in material flows such as hot water to be discharged, cooled air to be vented, the embodied energy in processed materials, etc..., and be able to calculate heat from different forms of precursor energy.

In this context, this work aims to carry out a detailed energy audit of a selected building at the University of Tlemcen (Chetouane campus). The goal is to assess its current energy performance, identify inefficiencies, and recommend practical, cost-effective solutions that

align with national energy conservation goals and international best practices. Through this work, the university can contribute meaningfully to the country's energy transition, while setting an example for other tertiary institutions across the region.

Problem Statement

Energy management aims to guide energy demand toward greater efficiency in the consumption system, through a national energy consumption model within the framework of the national energy policy.

The national energy consumption model, as a reference framework for guiding and managing energy demand, is based on the following energy options:

- The prioritized and maximal use of natural gas, especially for final thermal uses.
- The targeted use of electricity for its specific applications.
- The promotion of renewable energy sources.
- The gradual reduction of petroleum products share in the national energy consumption balance.
- Energy conservation, energy substitution, and energy savings at the levels of production, transformation, and use.

All countries that signed the Kyoto Protocol have used energy audits as a tool to improve energy performance. Meanwhile, our key questions are:

- ❖ What can be done to optimize the energy performance of infrastructures, such as the Faculty of Technology, at an optimal cost?
- ❖ What is the profitability of these improvements?

Hypotheses

To address these issues, we propose the following hypotheses:

- The design of the blocks is one of the most influential factors affecting the final energy balance, compared to technological or social factors.
- It is necessary to compare the theoretical consumption to the actual consumption of an existing building, so that adopting an audit based solely on real data provides reliable results on the consumption of each block.

Objectives

Our study falls within the framework of defining an energy management strategy for the Faculty of Technology in Chetouane-Tlemcen. It aims to:

- Highlight and identify in advance the areas with the highest energy consumption in order to take action and thereby improve the energy performance of the structure.
- Identify the causes of poor energy performance and follow up by formulating general recommendations aimed at improving energy efficiency.
- Carry out an assessment of the costs associated with the proposed improvement solutions.

Research Method

What motivated us to carry out our study is the reality on the ground in our faculty, where we observed shortcomings in energy audits, particularly in the tertiary sector. Our objective was to attempt to establish the steps of a simplified audit procedure, based on recognized methods and adapted to our context.

We first justified the relevance of the topic by emphasizing the importance of energy consumption in this sector. We then reviewed energy auditing its definitions, procedures, tools, and objectives both in international literature and within Algerian regulations.

Through examples of audits from around the world and within Algeria, we were able to make comparisons and define the methods, tools, and reports involved in an audit. We aligned with the APRUE methodology because it is very clear and practical. This integration allowed us to define the tools (questionnaires, levels of research investigation) for a reinterpreted approach adapted to the Algerian context. The results were then discussed in order to address and verify our working hypotheses.

Chapter 1: Literature Review

Introduction

As energy demand continues to grow particularly within the energy intensive building sector countries worldwide face the urgent task of integrating sustainable practices into their energy policies. This is particularly critical for developing countries in the Global South, where reconciling economic development with environmental preservation poses a significant challenge. The Johannesburg Summit in 2002 clearly emphasized the global importance of this issue.

To address this, a global commitment is needed to prioritize energy efficiency, limit greenhouse gas emissions, ensure equitable access to energy, and promote accountability at all levels. These efforts are central to both planetary sustainability and economic resilience.

In line with this global agenda, Algeria has adopted sustainability into its energy strategy by advancing the use of renewable energy sources. This approach reflects a broader shift towards environmentally conscious and economically sustainable development.

This chapter aims to analyze key global trends in energy production and consumption, provide an overview of Algeria's energy profile, and assess the country's strategic response to current energy challenges.

1.1 Global Production and Consumption of Energy

Globally, the building sector is the largest consumer of energy. This sector increasingly tends to play a major role in the economic context.

The global energy landscape has evolved in the past few years, with recent data showing steady demand growth, energy consumption increased, driven by emerging economies like China and India, while advanced economies saw slower growth or declines. Fossil fuels continue to dominate as showing in (Figure 2), but renewables are gaining ground, particularly in electricity generation [5].

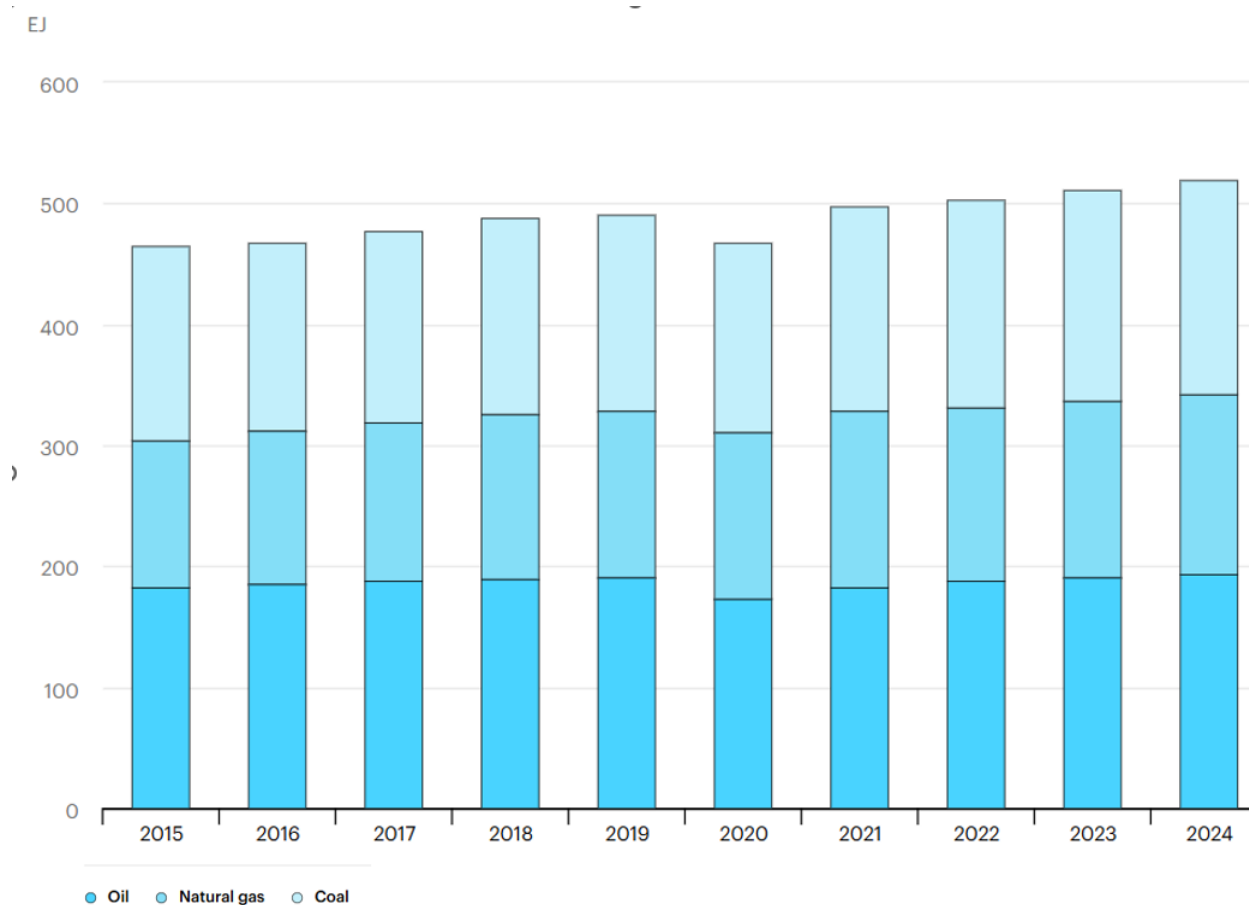


Figure 2.Global fossil fuel demand (2015-2024)

1.1.1 Energy Demand Growth

Global energy demand has grown steadily, driven by economic recovery and structural shifts in energy use.

Energy demand increased by 1.1% in 2022, reaching a record high but slower than the 5.5% growth in 2021. This reflected post COVID recovery tempered by disruptions from the Russia-Ukraine conflict and China’s economic slowdown [5].

In 2023 demand grew by 1.8%, exceeding the 2010-2019 average of 1.3%, Emerging economies drove this growth particularly BRICS nations with 42% of global

consumption and China at 6.6% and India at 5.1%. OECD countries saw a 1.5% decline, with the EU dropping by 4.2% due to weak industrial activity [6].

Meanwhile in 2024 demand rose by 2.2%, nearly twice the 2013-2023 average of 1.3%. Emerging and developing economies accounted for over 80% of this growth, though China’s growth slowed to under 3%. Advanced economies saw a 1% increase, marking a recovery from 2023 declines, this table shows the total energy supply in EJ and the growth rates in energy fields in 2022 to 2024 (Table 1-1).

Table 1. Total energy supply and growth rates

Source	Total energy supply (EJ)			Growth rate	
	2022	2023	2024	(2022–23)	(2023–24)
Total energy supply	622	634	648	1.80%	2.20%
Renewables	89	92	97	3.10%	5.80%
Nuclear	29	30	31	2.20%	3.70%
Natural gas	144	145	149	0.70%	2.70%
Oil	188	192	193	1.90%	0.80%
Coal	172	175	177	2.00%	1.20%

The world’s energy consumption has grown steadily with 2023 data showing a record 634 EJ, a 2% increase from 622 exajoules 2022 driven by rising electricity demand, fossil fuels continued to dominate accounting for 81.5% of the energy mix in 2023. Oil contributed 32%, coal 26%, and natural gas 23%, while renewable energy sources made up 14.6%, and nuclear energy comprised the remaining 3.9% [7].

Global energy consumption experienced a significant acceleration in 2024 reaching nearly 650 EJ, growing by 2.2%, surpassing the annual average of 1.3% observed between

2013 and 2023, This surge was driven by various factors, including extreme weather conditions, which contributed an estimated 0.3 percentage points to the overall growth. [5]

Renewables played a significant role, accounting for the largest share (38%) of the growth in global energy supply, followed by natural gas (28%), coal (15%), oil (11%), and nuclear (8%) (Figure 3).

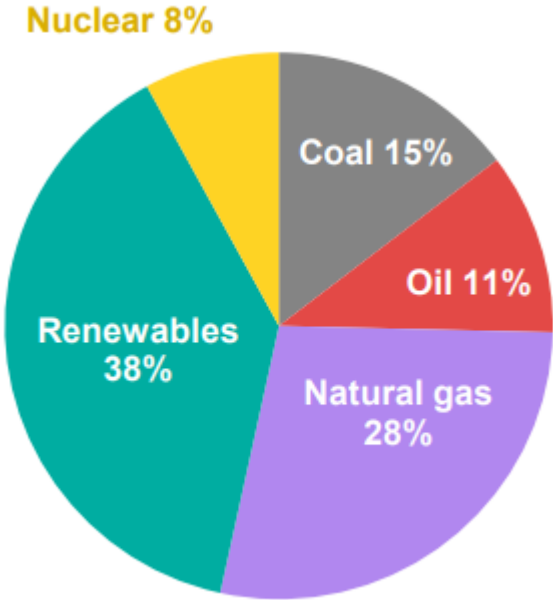


Figure 3. Share of energy demand growth by source, 2024

Emerging and developing economies accounted for over 80% of global energy demand growth. China experienced a slowdown in energy demand growth to under 3% in 2024, while India saw the second-largest rise in energy demand in absolute terms, exceeding the combined increase in all advanced economies. Advanced economies also saw a return to growth in energy demand, rising by almost 1%. The United States recorded the third-largest absolute demand growth in 2024, and the European Union returned to

growth for the first time since 2017, (Figure 4) shows the change in the energy demand. [5]

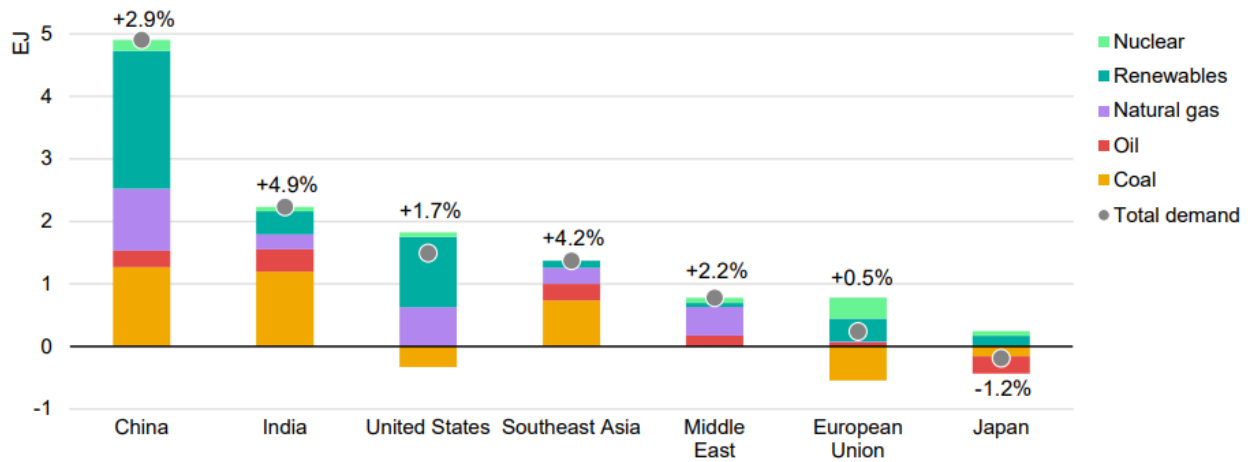


Figure 4.Change in energy demand in selected regions, 2023-2024

1.1.2 Energy Production and Fuel Mix

Global oil demand growth slowed markedly in 2024, with consumption rising by 0.8% (approximately 830,000 barrels per day) to 193 EJ after a 1.9% jump in 2023, influenced by the end of the post pandemic mobility rebound, slower industrial growth and increased electric vehicle adoption.

Oil's share of total energy demand fell below 30% for the first time in 50 years after peaking at 46%. Growth was led by petrochemicals and aviation each accounted for around half of oil demand growth, while road transport demand fell in energy terms (Figure 5). [5]

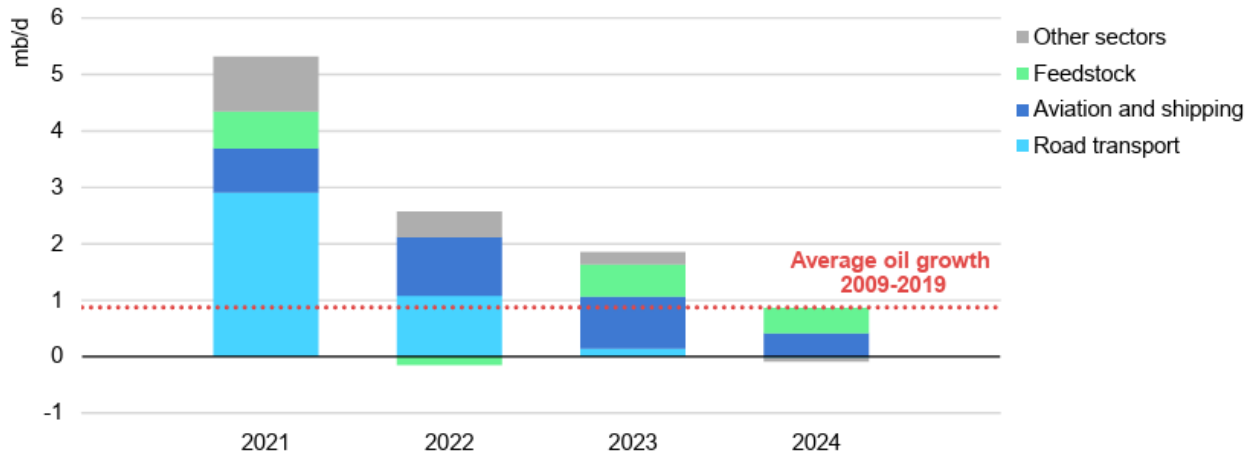


Figure 5.Global oil demand growth by sector, 2021-2024

China's oil demand growth slowed sharply to 0.8% in 2024, following a record 8.7% increase in 2023, the US oil demand was flat remaining at 4.3% below 2019 levels, non-feedstock uses declined by 7%, while petrochemical use rose by nearly 18%. [5]

Advanced economies saw a 0.1% demand fall, 5.4% below 2019 levels, concentrated in road transport due to efficiency standards, electric vehicles, and remote work, India was the largest single global oil demand growth source in 2024, with gasoline use up 41.7% from 2019, we can see the change in oil demand in selected regions (Figure 6).

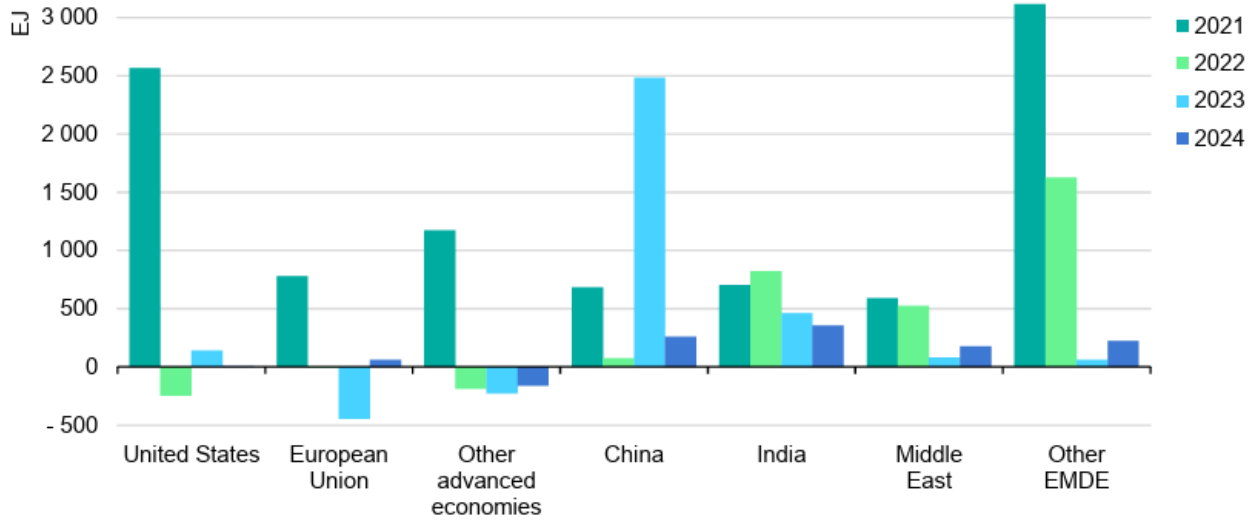


Figure 6.Change in oil demand by region, 2021-2024

Following the supply shock of 2022 and 2023, natural gas markets returned to structural growth in 2024 reaching a new all-time high, this growth was driven primarily by emerging market and developing economies which accounted for over three-quarters of the increase, Global gas demand increased by 2.7%, or 115 billion cubic meters (bcm), surpassing the annual average growth rate from 2010 to 2019. [5]

Industry and electricity generation were the main contributors to higher gas consumption, accounting for 75% of the incremental demand, extreme weather conditions, such as heatwaves in China, India, and the United States, boosted gas use in power generation.

Gas demand in emerging Asia expanded by about 6% in 2024, driven by China and India, North America saw a rise of close to 1.8% in 2024, primarily supported by gas demand for electricity generation. The European Union experienced a rise of about 1% in 2024, while gas demand for power generation fell by around 5% due to increased renewable electricity generation, we can see the change in gas demand in (Figure 7). [5]

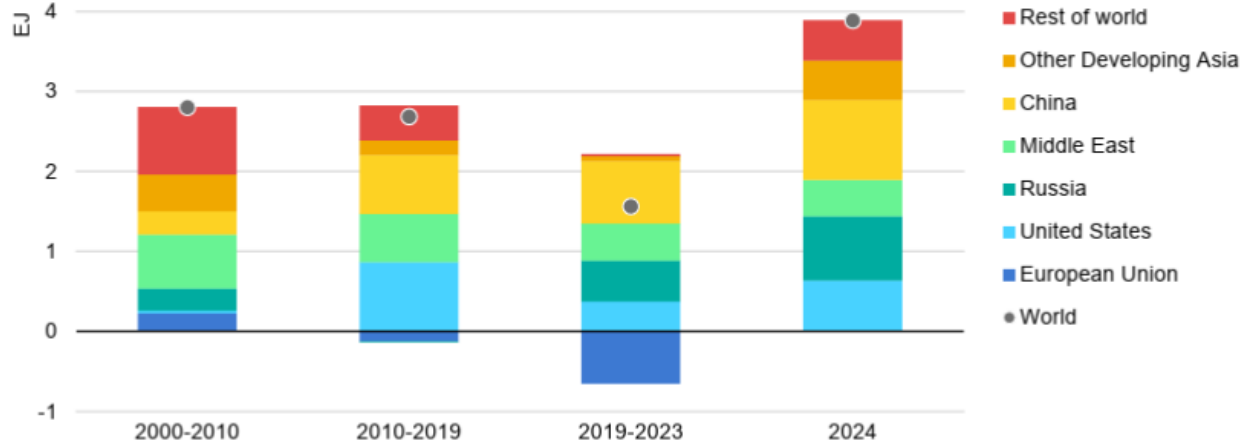


Figure 7.Change in natural gas demand by region, 2000-2024

As for coal, the global coal demand grew by 1.2% in 2024 reaching an all-time high of 177 EJ, though the growth rate has slowed since the post-COVID rebound, power generation remains the primary driver accounting for two-thirds of global consumption, with global coal power generation growing by nearly 1% to 10 700 TWh, driven by record temperatures and cooling needs especially in China and India.

China Coal demand grew by 1.2% accounting for 58% of global coal consumption, power generation was the primary driver, while industrial coal use declined due to reduced steel and cement production. [5]

India coal demand rose by 5.5% driven by strong economic growth and increased power and industrial use, southeast Asia coal consumption grew by 8% led by industrial use in Indonesia and power generation in the Philippines and Vietnam.

Advanced economies coal demand continued to decline, falling by 4% in the United States and over 10% in the European Union, the UK eliminated coal power capacity in 2024. [5]

1.1.3 Electricity Demand and Generation

Global electricity demand surged in 2024, increasing by 4.3%, a significant rise from the 2.5% growth in 2023, This acceleration was widespread with almost all regions experiencing higher electricity consumption growth compared to the 2012-2022 average, global electricity consumption increased by 1 080 TWh nearly twice the annual average of the past decade. [5]

China accounted for the largest share of electricity consumption growth, increasing by more than 550 TWh (7%), almost matching the average annual global increase over the previous decade, advanced economies saw a dramatic reversal, with electricity consumption increasing by 230 TWh, led by growth in the United States driven by strong cooling demand, data center growth, and industrial production, The European Union's electricity consumption grew by about 1.5% in 2024. [5]

The buildings sector was a key driver, with global electricity consumption in buildings increasing by more than 600 TWh (5%) accounting for nearly 60% of total electricity consumption growth. Rising demand for air conditioning, bolstered by severe heatwaves, and demand from new data centers were key factors.

The industry sector made up nearly 40% of total growth in electricity demand in 2024, driven by increased activity in electro-intensive manufacturing and broader industrial growth, the continued uptake of electric vehicles raised electricity consumption in the transport sector by over 8% in 2024 as we can see in (Figure 8).

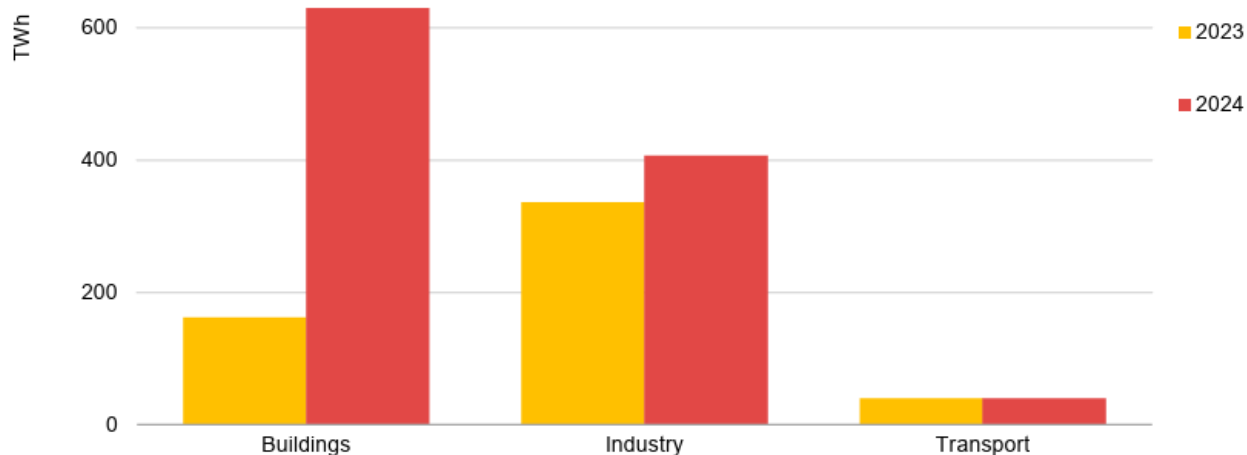


Figure 8. Annual change in electricity consumption by sector

Global electricity generation grew by over 1 200 TWh in 2024. Mirroring the rise in electricity demand, this annual increase of 4% represents a significant acceleration from the average growth rate of 2.6% seen between 2010 and 2023. [5]

The global electricity generation saw a significant transformation in its fuel mix, with renewables and nuclear power playing an increasingly dominant role, renewables supplied 32% of global electricity generation, and together with nuclear they contributed 40% for the first time.

Electricity generation from renewables rose by 10%, driven by record breaking expansion of solar PV capacity, as well as further growth in wind power and hydropower, solar PV and wind generation increased by a record 670 TWh, demonstrating the impact of these technologies.

Natural gas-fired generation also increased rising by 170 TWh, while coal-fired generation rose by 90 TWh, nuclear generation grew substantially, increasing by 100 TWh equaling the largest increase this century outside of the post-COVID rebound (Figure 9).

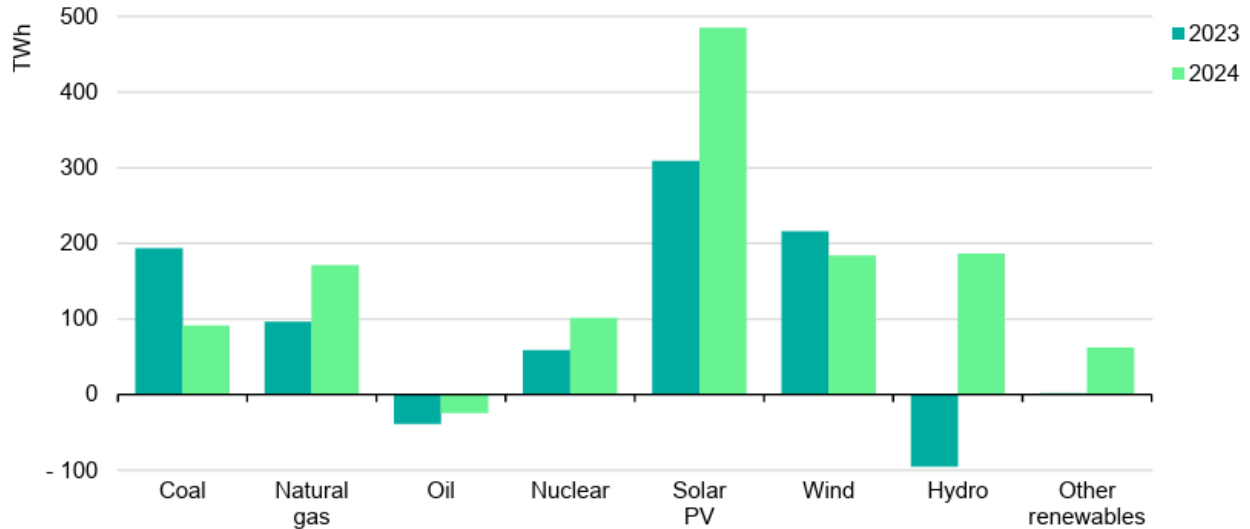


Figure 9. Annual change in global electricity generation by source

In the European Union, the combined share of solar PV and wind surpassed the combined share of coal and gas for the first time marking a significant milestone in the region's energy transition, the United States also saw growth in renewables with solar PV and wind's share rising to 16%, overtaking coal for the first time, China experienced a similar trend, with solar PV and wind reaching nearly 20% of total generation. [5]

1.2 Energy Production and Consumption in Algeria

Algeria's domestic energy consumption has risen sharply in recent years, total primary energy use grew by 7 % every year since 2020 reaching 70 million tonnes of oil equivalent (Mtoe) in 2023 compared with 44.6 Mtoe in 2017. [6]

National energy consumption increased by 3.2% to 72.2 Mtoe, driven by a 2.1% rise in final consumption, final consumption accounted for 75% of the total national consumption, the consumption of petroleum products increased by 5.5%, electricity by 3.2%, and natural gas by 1.6%, the structure of national energy consumption is dominated by natural gas (39%) followed by electricity (31%) and liquid products (22%) as we can see in (Figure 10). [8]

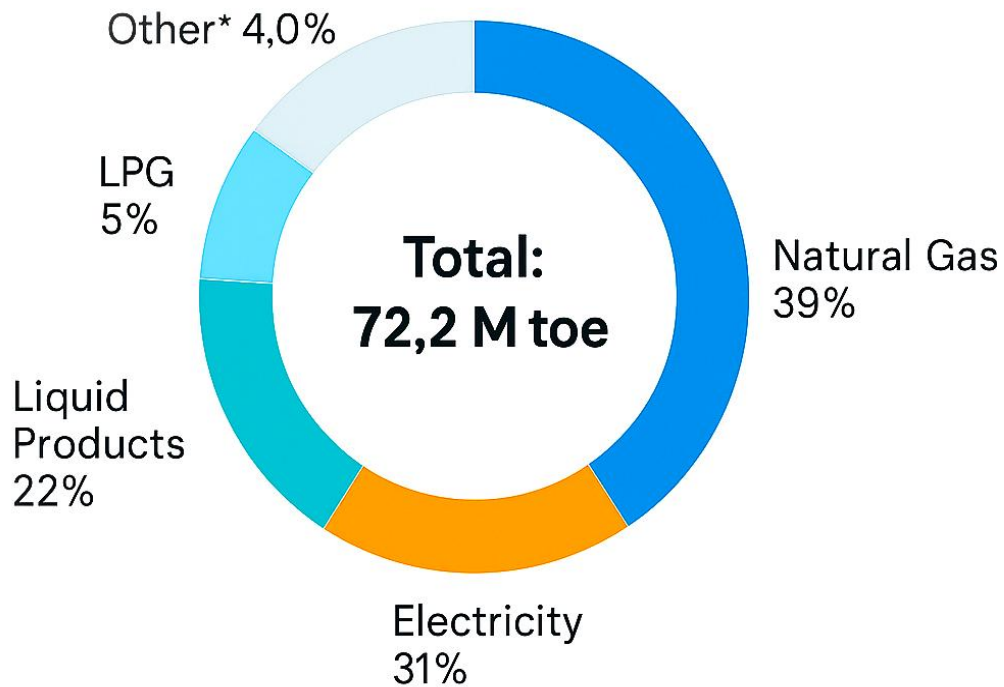


Figure 10. Structure of national consumption by form of energy

Algeria's energy sector saw a 3.0% increase in primary energy production in 2023 reaching 170 Mtoe, natural gas dominated the primary energy production structure at 59%, followed by oil at 30%.

primary electricity production from renewable sources increased by 6.1% to 723 GWh driven by higher output from hydroelectric and photovoltaic plants, despite this growth, renewables still constitute a modest 1% of the total national electricity production, with natural gas accounting for the remaining 99%. [8]

the following table shows the primary energy production in Algeria and the growth rate (Table 1-2).

Table 2.The primary energy production

Product	Units	2022	2023	Change (Quantity)	Change (%)
Natural gas	K toe	95,857	99,689	3,823	4.00%
	10 ⁶ m ³	101,436	105,482		
Crude oil	K toe	50,437	51,035	598	1.20%
	K tonnes	45,727	46,269		
Condensate	K toe	9,063	9,246	183	2.00%
	K tonnes	8,006	8,168		
Field LPG	K toe	9,833	10,111	278	2.80%
	K tonnes	8,333	8,569		
Primary electricity	K toe	164	171	7	4.20%
	GWh	681	723		
Solid fuels: Wood	K toe	18	8	-10	- 56.20%
	10 ³ m ³	91	40		
TOTAL	K toe	165,372	170,252	4,879	3.00%

Algeria remains a key player in hydrocarbon production, with proven natural gas reserves ranked among the top ten globally, the country achieved significant oil and gas discoveries in 2024 and launched multiple renewable energy projects including the construction of several solar power plants totaling hundreds of megawatts, such as a 200 MW plant in El Meghair and others in Tougourt and Ouled Jalal, the government targets an ambitious expansion to 15 GW of renewable capacity by 2035, focusing on solar, wind and hydro resources to reduce environmental impacts and enhance energy security. [9]

1.3 Global and Algerian energy intensity

1.3.1 global energy intensity

The primary energy intensity is the energy consumed per unit of GDP is a key indicator of energy efficiency, continued to slow in 2024, after improving at an average rate of around 2% annually from 2010 to 2019, the measure declined to 1.2% in recent years (2019-2023) and fell to around 1% in 2024, this slowdown is attributed to investment and manufacturing-intensive economic recoveries in major emerging market and developing economies like China and India, high energy demand due to extreme temperatures and poor growth in hydropower output leading to greater consumption of less-efficient coal power in some regions. [5]

In 2024, energy intensity improvements slowed in advanced economies after several years of rapid progress due to high energy prices and weaker economic conditions in energy-intensive sectors.

China and India saw faster energy intensity improvements, although still below pre-COVID-19 rates, the carbon intensity of total energy supply improved by 1.1% in 2024 resulting in an improvement in the CO₂ intensity per unit of economic activity of 2.1%, this is slightly slower than the average improvement seen over the last decade due to the slowdown in energy intensity improvement.

Electricity consumption growth has remained broadly in line with GDP growth over the last decade amid wider electrification trends, the electricity intensity of GDP increased by 1%, as electricity demand growth exceeded the increase in GDP in 2024.

The following figure demonstrates the decline in global energy intensity improvement in 2023 and 2024 (Figure 11). [5]

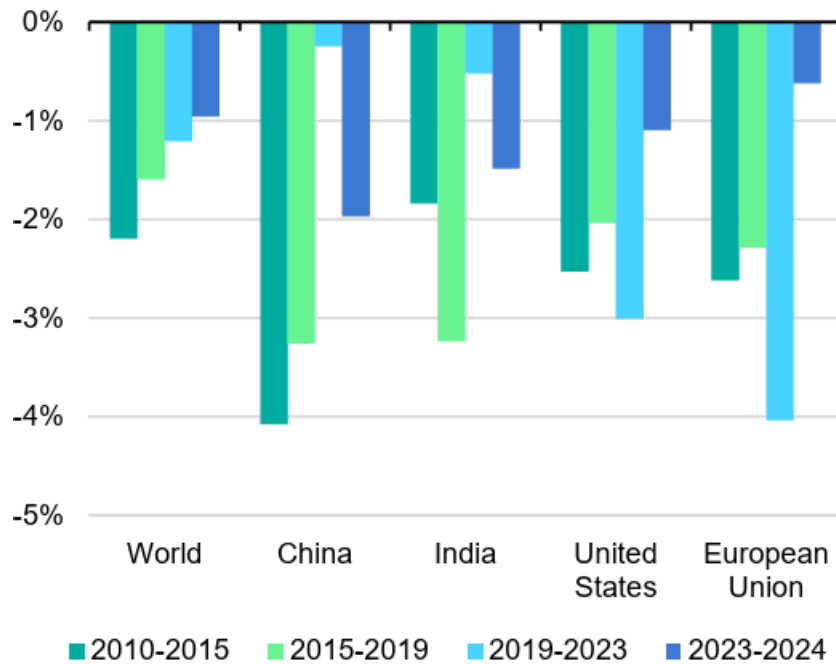


Figure 11. Average annual rate of energy intensity improvement, 2010-2024

1.3.2 Algerian energy intensity

Algeria’s energy intensity profile is characterized by a relatively high level of energy consumption per unit of economic output, reflecting the country’s dependence on fossil fuels, structural economic factors, and ongoing transitions in its energy sector, this fossil fuel dependence contributes to elevated energy intensity as energy losses occur within the upstream oil and gas sectors including extraction, processing, and liquefied natural gas operations, these losses reduce overall energy efficiency and increase the total energy required per unit of GDP. [10] [11]

In Algeria, energy intensity of GDP has declined more slowly between 2000 and 2022, the intensity fell by 35 %, reflecting both rising energy demand in non-efficient sectors and improvements in power-plant efficiency, despite government measures Algeria’s intensity remains above the OECD average, underscoring the need for deeper efficiency actions especially in buildings and industry. [11]

Over the past decade, Algeria has witnessed a substantial rise in energy consumption. Per capita energy use increased from about 12,243 kWh in 2010 to roughly 15,458 kWh in 2023, highlighting growing demand across the residential, industrial, and transport sectors.

In 2024, Algeria’s energy intensity was estimated at about 4.92 megajoules (MJ) per US dollar (PPP). This means the country used nearly 5 MJ of energy to produce one dollar of economic output, adjusted for purchasing power parity, the increase from 4.66 MJ in 2022 to 4.92 MJ in 2024 shows that Algeria’s energy use is rising faster than its economic growth. This may be due to greater energy needs in oil and gas production and slow progress in improving energy efficiency [12].

We can see the annual change in energy intensity per GDP in Algeria and worldwide in (Figure 12).

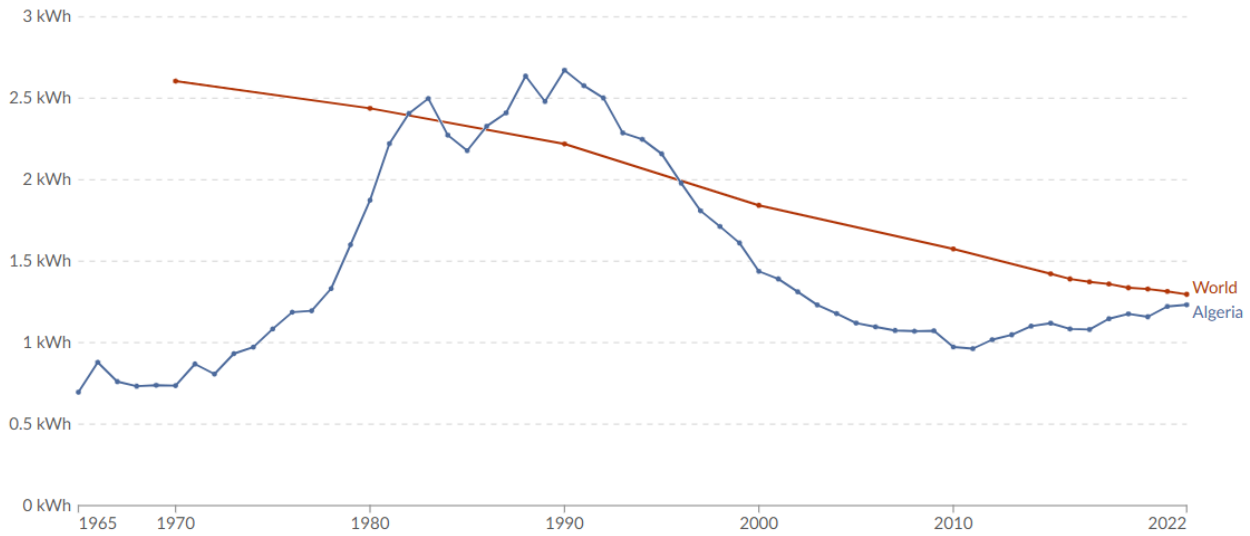


Figure 12.Annual change in energy intensity per GDP

1.4 Algerian Energy Strategy for Sustainable Development

Algeria's economy is heavily reliant on oil and gas, which account for over 90% of exports, 20% of GDP, and nearly half of government revenues. This dependency exposes the country to global price volatility and fiscal instability, while also limiting economic diversification and job creation. The government recognizes that maintaining this model is unsustainable, both economically and environmentally.

Algeria's approach is guided by national and international frameworks, notably the UN Sustainable Development Goals (SDGs), particularly SDG 7 (ensuring access to affordable, reliable, sustainable, and modern energy) and SDG 13 (combating climate change). The national vision, articulated in "Vision Algérie 2030," emphasizes economic diversification, environmental sustainability, and social equity as core pillars for future growth. [19]

In the last few years Algeria has updated its National Energy Efficiency Program (PNME), targeting:

- A 15% reduction in total energy consumption by 2035
- Installation of 22,000 solar water heaters in the residential sector
- Improved energy audits in public buildings and institutions
- Development of solar PV systems in schools, hospitals, and universities

1.4.1 Renewable Energy Expansion

When we talk about renewable energy the first sectors to work on is Solar and Wind Power, Algeria possesses some of the world's highest solar irradiation levels (over 2,000 kWh/m² annually), making solar energy the cornerstone of its renewable strategy. The National Renewable Energy Development Strategy (2015–2030) aims to install 13.5 GW of solar capacity by 2030, with a broader target of 15 GW from renewables by 2035.

As for Wind Energy it is still less developed than solar, wind projects are being piloted particularly in the country's southern regions. [20]

1.4.2 National Legal and Regulatory Framework

Algeria's energy sector is governed by a series of laws and regulations aimed at managing its hydrocarbon resources, promoting renewable energy, ensuring energy efficiency, and protecting the environment.

- Law No. 19-13 (December 2019): This revised hydrocarbon law is central to Algeria's strategy to revitalize its oil and gas sector, it introduces more favorable fiscal terms, simplified procedures, and a greater emphasis on collaboration to attract foreign investment particularly for the development of unconventional resources, the law allows for production sharing, concession, and risk service contracts, offering flexibility to international oil companies. [21]
- Law No. 05-07: This earlier law established the foundational regulatory framework for oil and gas activities and created key regulatory authorities. [21]
- Law No. 04-09 (August 2004) on the promotion of renewable energies in the framework of sustainable development: This law lays the groundwork for Algeria's national renewable energy program, its objectives include promoting domestic renewable energy sources, curbing greenhouse gas emissions, conserving fossil fuel resources, and contributing to sustainable development, it also established a National Observatory Centre for the Promotion of Renewable Energy. [21]
- Law No. 99-09: a law on Energy Management provides a basis for energy efficiency measures, policies promote efficient lighting, thermal insulation, and the use of natural gas in transport, standards and labeling programs for household appliances are also being implemented, aligning with EU eco-design regulations. [21]
- Law No. 16-09 on Investment Promotion: This is a key legislative instrument governing foreign investment in Algeria, the National Agency of Development of Investment is responsible for registering, promoting, and facilitating investments.[21]

Conclusion

In summary, this chapter has reviewed the global and Algerian energy landscapes, emphasizing rising energy demand, evolving fuel mixes, and the growing importance of sustainable development. While global efforts increasingly prioritize renewable energy and efficiency, Algeria remains heavily reliant on fossil fuels, particularly natural gas. However, the country has taken significant steps toward reform, including national strategies and legal frameworks aimed at diversifying energy sources and improving efficiency. Algeria's high energy intensity and dependence on hydrocarbons highlight the need for deeper reforms particularly in the building and industrial sectors.

These insights lay the groundwork for the following chapters, which will examine practical approaches particularly energy audits as key tools for improving energy performance and advancing Algeria's energy transition, a subject we will explore in detail in the next chapter.

Chapter 2: Energy audit

Introduction

Nowadays, the world is suffering from many problems that cause major harm to all mankind, the major problems are climate change and pollution, in recent years energy auditing and planning, for both existing and new buildings has attracted increasing interest due to growing environmental concerns.

Energy auditing is an important part of managing energy efficiently, it helps organizations understand how energy is used across a site by measuring both the amount of energy coming in and how it is used, this process can highlight areas where energy is wasted and suggest ways to reduce costs, improve equipment maintenance, and maintain quality.

As energy prices rise and environmental rules become stricter, energy audits have become even more valuable, they give a clear picture of how energy is used, point out problems, and recommend improvements. With the help of new technology and standard methods, energy audits are now more accurate and useful than ever, they help organizations choose the best energy sources, track energy costs, and adopt energy saving tools and strategies.[13]

In general, an energy audit consists of translating energy saving ideas into reality, providing technically feasible solutions with economic and other organizational considerations within a specific timeframe, the main objective of an energy audit is to find ways of reducing energy consumption per unit of production or cutting operating costs.

This chapter explains the main ideas, methods, and uses of energy auditing to help us understand how it works and why it matters.

2.1 Fundamentals of energy audits

2.1.1 Definition and Importance

An energy audit is a systematic and comprehensive review of a facility's energy requirements, consumption patterns, and operational practices, the primary objective is to

identify and quantify opportunities for energy savings, reduce operational costs, and minimize environmental impact, particularly CO₂ emissions.

Energy audits play a key role in improving energy efficiency, supporting building renovations, and helping move toward carbon neutrality, they are often the first step in creating a strong energy management plan giving a clear picture of how energy is used and where it can be saved, energy audits also suggest practical and cost-effective ways to improve energy use, the main goal is to use and buy energy in the best way possible reducing waste and lowering costs without harming productivity or service quality.[14]

Globally, buildings are significant energy consumers accounting for a large portion of overall energy use, universities with their expanding facilities and increasing student populations often experience rising energy consumption and associated costs, making energy audits particularly pertinent, in Algeria regulations mandate energy audits for tertiary institutions when their energy consumption surpasses a specific threshold (500 Tonnes of Oil Equivalent), highlighting the national importance of such assessments.[15]

2.1.2 Types of energy audits

Energy audits can vary in scope and detail, generally categorized into different levels to suit specific needs and objectives, common classifications include:

- Walk-through audit (Preliminary audit or ASHRAE Level 1): This is a basic assessment involving a site visit to visually inspect the facility, review energy bills, and identify low cost-no-cost energy saving opportunities, it provides a general overview of energy consumption and potential areas for improvement.
- General audit (Detailed audit or ASHRAE Level 2): This level involves more detailed data collection, measurements, and analysis, it includes an in-depth review of energy consuming systems, quantification of energy uses and losses, and a more thorough economic analysis of proposed energy conservation measures (ECMs), ASHRAE level 1 and 2 guidelines are frequently employed in university settings

- Investment grade Audit (ASHRAE Level 3): This is the most comprehensive type of audit providing a detailed engineering analysis of potential capital-intensive projects, it typically involves continuous site monitoring, detailed system modeling, and rigorous financial analysis to provide a high level of confidence for major investments.

The choice of audit level depends on factors such as the facility's complexity, energy consumption, and the organization's energy management goals. [16]

2.2 Energy audit methodology

A structured methodology is essential for conducting an effective energy audit, while specific steps may vary, a general framework typically includes the following phases:

2.2.1 Pre-audit phase

The pre-audit phase is crucial for defining the scope, goals, and methodology of the energy audit, it begins with preliminary meetings between the audit team and facility management to understand the energy use profile and specific objectives of the audit. [14]

A preliminary site walkthrough is conducted to identify the major energy-consuming systems and operational patterns, historical energy consumption data such as utility bills and previous maintenance records are collected and reviewed to develop a baseline for comparison.

Key activities include:

- Stakeholder consultation and expectation setting
- Review of utility bills and historical consumption
- Preliminary site inspection
- Identification of high-energy-use areas
- Development of a detailed audit plan and schedule

The goal of this phase is to establish a foundation for data collection, clarify logistical considerations, and ensure alignment with client expectations.

2.2.2 Audit execution phase

The audit execution phase involves detailed data collection, on-site measurements, and technical analysis of energy systems, this phase seeks to quantify energy flows and identify inefficiencies in the facility's energy usage.

Auditors typically use tools such as data loggers, thermal cameras, flow meters, and power analyzers to monitor real-time energy usage across various systems, including lighting, HVAC, compressed air, and industrial machinery, data is then analyzed to identify Energy Conservation Measures (ECMs) and assess their technical and financial viability. [14]

Key activities include:

- On-site measurements and instrumentation
- System performance assessment
- Identification of losses and inefficiencies
- Development of ECMs
- Financial evaluation (e.g., payback period, ROI, NPV)

This phase is often the most time-intensive but yields the most actionable insights.

2.2.3 Post-Audit Phase

The post-audit phase centers on synthesizing data into a comprehensive report and facilitating the implementation of energy-saving recommendations, the report typically includes a summary of findings, detailed analysis of ECMs, and cost-benefit evaluations, stakeholder presentations are often held to communicate the results and discuss potential implementation strategies.

Follow-up actions may include staff training, installation of energy monitoring systems, and establishing protocols for measurement and verification of energy savings in accordance with standards such as the International Performance Measurement and Verification Protocol. [17]

Key activities include:

- Compilation of audit findings into a report
- Presentation to stakeholders
- Roadmap for ECM implementation
- Staff training and knowledge transfer
- Ongoing monitoring and verification planning

The following figure summarizes the energy audit phases in a simple four steps (Figure 13)

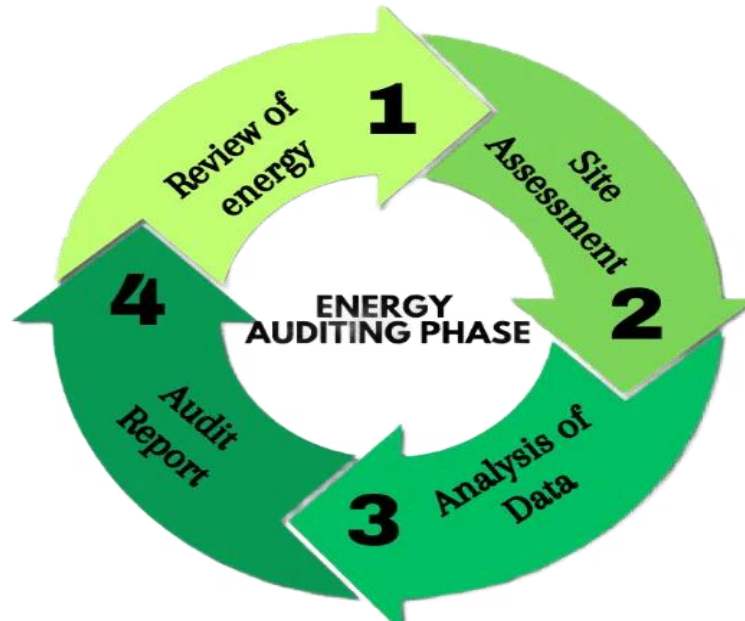


Figure 13. Energy audit simple steps

2.3 Parameters to measure during the energy audit

Accurate measurement is a key part of any energy audit, it requires instruments that are precise, reliable, easy to use, and built to last, though they can be expensive, these tools help collect the data needed to assess how energy is being used, to get meaningful results data should be accurate and collected over a period that reflects normal operations.

However, in real situations full and continuous data is rarely available. Therefore, auditors must regularly check the condition of the instruments and consider possible measurement errors, this helps ensure that the data is trustworthy, the success of the measurement phase depends on using high-quality instruments that can perform well under real operating conditions.

The auditor must regularly verify the operational condition and maintenance status of measurement instruments and evaluate potential errors to ensure data reliability.

Measurement activities using both portable and installed devices typically take place during the implementation phase and provide immediate or short-term performance data, to obtain accurate and meaningful results, it is advisable to conduct measurements over a duration that is representative of each equipment's actual usage, the parameters usually monitored during an energy audit can cover the following elements [18]:

- Energy consumption: Electricity, natural gas, fuel oil, coal, renewable energy production
- Electrical parameters: Voltage, current, active power, reactive power, and apparent power
- Thermal parameters: Air, water, and surface temperatures ($^{\circ}\text{C}$), heat transfer fluid flow rates (m^3/h), pressure
- Ventilation and air quality: Airflow rates, relative humidity, CO_2 emissions
- Occupancy and usage behavior: Operating hours, Number of occupants, Operating hours

2.4 Energy audit tools

To help people better understand and analyze how they use energy whether they are experts or not, different tools have been developed over time. These tools include both measuring devices, documents or software to help with decision-making. In our project, we used a thermal camera, energy bills, questionnaires, and some software to measure energy use, find out exactly where heat was being lost, and work on improving the energy efficiency of our faculty buildings.

2.4.1 Measurement tools (thermography)

To measure the actual energy use of each building, the auditor uses different tools depending on the building's specific characteristics. In our case, we used the Testo 890 thermal camera, which helps quickly and reliably detect problems and weak points in materials and components.

The Testo 890 thermal imager is an invaluable tool for conducting energy audits, offering precise and detailed thermal analysis essential for identifying energy inefficiencies in buildings. With its high-resolution imaging capabilities, including a standard resolution of 640 x 480 pixels that can be enhanced to 1280 x 960 pixels through Super Resolution technology, the Testo 890 allows auditors to detect even the smallest temperature variations. This sensitivity is crucial for pinpointing issues such as insulation failures, air leaks, and thermal bridges that contribute to energy loss. The imager's interchangeable lenses provide flexibility for various inspection scenarios, enabling users to capture wide-field images or focus on specific areas of concern. Additionally, features like the panorama image assistant assistant for capturing large areas, while the integrated digital camera allows for the documentation of thermal images alongside visible-light images, enhancing the clarity of reports.

Overall, the Testo 890 equips energy auditors with the tools needed to conduct thorough evaluations and recommend effective energy-saving measures. [22]



Figure 14. Testo 890 thermal camera

2.4.2 Documents

Documentation serves as a key audit tool no action is possible Without it, particularly energy bills, which provide insight into the actual energy consumption of buildings, and architectural plans. However, these plans were not available in any accessible location. Therefore, in order to proceed with our work, we had to use the manually surface area estimation of each block within the faculty that used in the study of 2019. [23]

In addition, the energy audit of the Faculty of Technology required taking into account billing data over several years. After a significant effort and considerable delays that disrupted our timeline, we were able to access the last three years of energy bills, which allowed us to establish a reliable consumption profile.

2.4.3 Software

We employed software tools capable of calculating and comparing both energy consumption and thermal losses, these tools are used during the design phase to simulate the site's projected thermal performance, and during the analysis phase to analyze actual performance, identify inefficiencies, and propose targeted improvements.

IRSoft

The IRSoft software is a comprehensive tool designed for analyzing and processing thermal images captured by Testo thermal imagers. Here are the key functionalities that IRSoft offers:

- **Image processing and analysis:** IRSoft enables users to easily process and analyze infrared images, it includes extensive investigative functions that allow for professional thermal image processing such as highlighting critical temperature ranges.
- **Measurement point management:** Users can set multiple measurement points without limitations, which is crucial for identifying hot and cold spots in thermal images. This feature enhances the accuracy of thermal assessments, especially in applications like energy audits.
- **Reporting capabilities:** The software includes a report wizard that guides users through creating professional thermography reports. Users can choose from various templates to document their findings clearly and comprehensively including all relevant information about the inspection.
- **Visualization of temperature Data:** IRSoft can visualize critical temperatures in the images, highlighting areas that exceed or fall below specified limits. This functionality is essential for quickly identifying potential issues in building inspections or electrical systems.
- **Integration with thermal imagers:** The software allows for direct control of connected Testo thermal imagers, enabling users to adjust settings and capture images seamlessly. This integration streamlines the workflow for thermographers.
- **Archiving and documentation:** Users can archive thermal images and associated data, making it easier to manage and retrieve information for future reference or follow-up inspections.

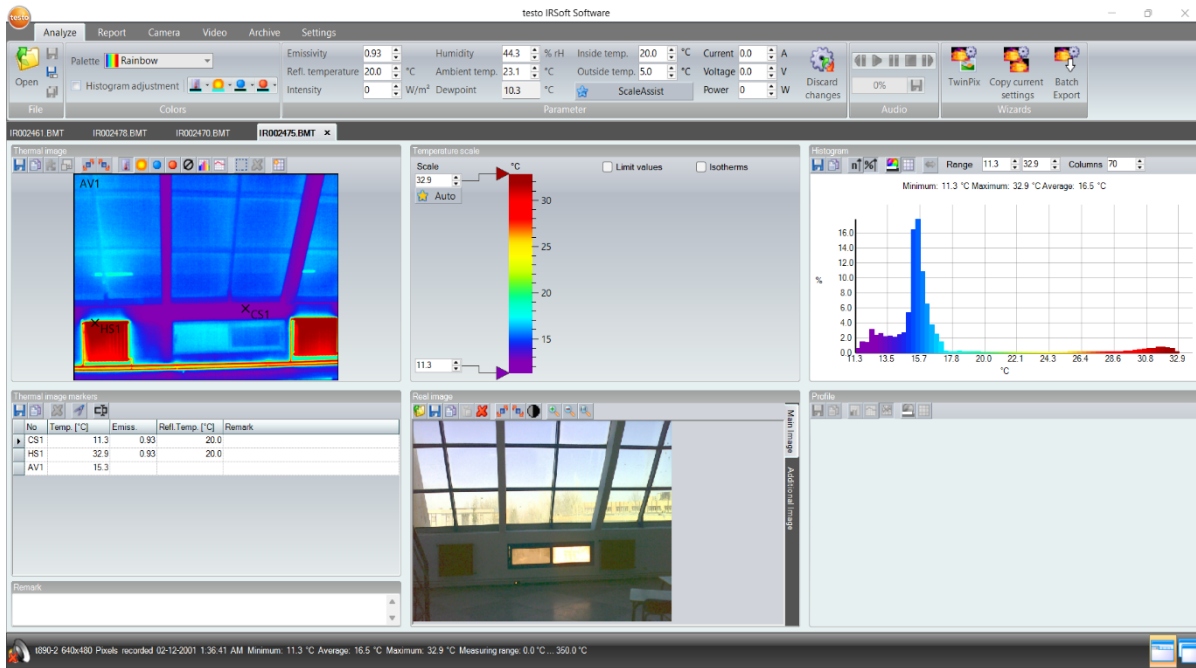


Figure 15. IRSoft interface

RETScreen

RETScreen is a comprehensive clean energy management software developed by the Government of Canada, it is designed to assist professionals and decision-makers in evaluating the feasibility and performance of renewable energy and energy efficiency projects.

RETScreen allows professionals to identify, assess, and optimize the technical and financial viability of potential projects, measure and verify the actual performance of facilities and manage portfolios of multiple energy projects. The software integrates extensive databases including climate data and benchmarks, to facilitate informed decision-making. Additionally, RETScreen supports various analyses such as energy modeling, cost analysis, and greenhouse gas emissions assessments, making it a comprehensive tool for promoting sustainable energy solutions across different sectors.[24]

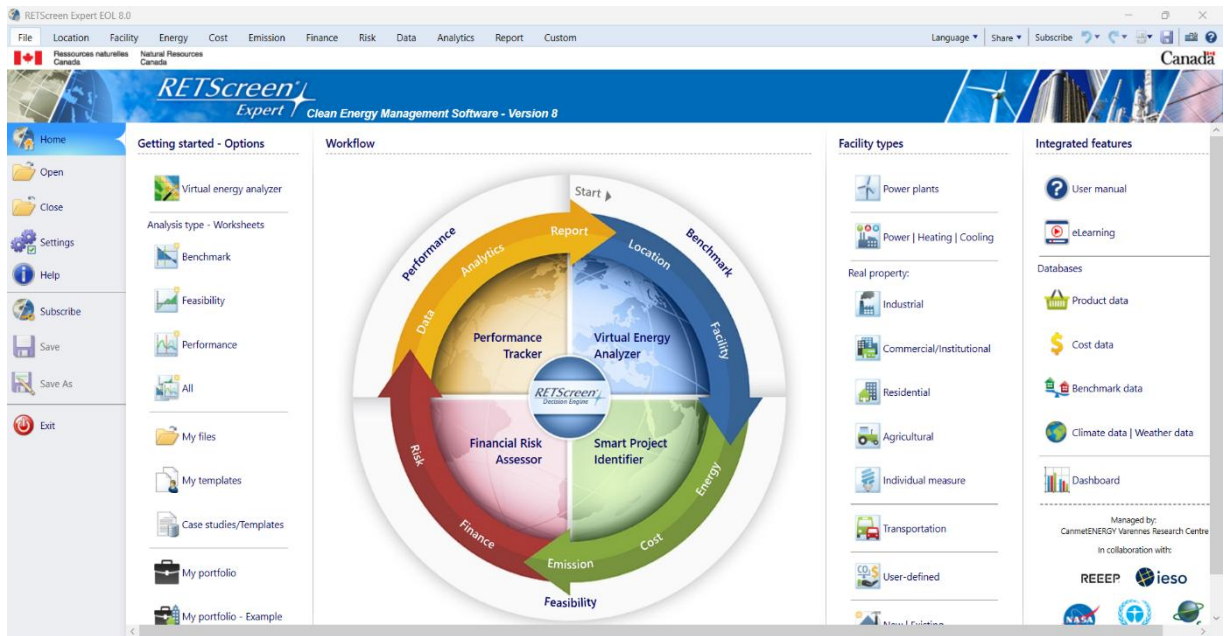


Figure 16. RETScreen interface

Conclusion

With the preliminary phase completed, we had acquired a clear understanding of the audit methodology, the materials and tools to be used, as well as the core objectives and purpose of our work.

This foundation allowed us to transition into the theoretical framework, paving the way for the operational phase which focuses on the analysis, identification, and evaluation of energy consumption across the entire facility, as well as an assessment of the site's current energy profile. Analyzing the energy and thermal aspects of a facility is a critical factor not only for achieving energy savings and cost management, but also for ensuring a higher level of overall comfort. This will be the focus of the chapters that follow.

Chapter 3: Audit implementation procedure

Introduction

An energy audit is one of the most effective methods to identify inefficiencies and reduce losses. Instead of auditing a single block, we extended the study to the entire Faculty of Technology. This chapter presents the faculty's current energy situation (surface area, consumption, category) using tariff analysis, EU energy classification, and regression-based modeling to separate base loads from heating demand. Each block is assessed with EN 15217/ISO 52000 activity factors; Calculations are then applied to quantify actual energy losses in every block.

3.1 The current state of the site

3.1.1 The faculty's total energy consumption

In relation to the faculty's energy plan, the energy audit requires both measurements and utility bills, which serve as the basis for determining the faculty's actual energy consumption. The necessary data were collected, and the real consumption was calculated for the last three years (2022–2024) using SONELGAZ invoices.

3.1.1.1 Electricity

The billing of electricity supplied by the Distribution Companies responsible for commercialization is carried out uniformly across the entire national territory, based on the following **pre-tax rates** as shown in table 3. [25]

Table 3. Electricity tariffs

Tariff Code	Service Type	Fixed Charges (DA/Month)	Capacity Charges (DA/kWh/Month)	Energy Consumption Charges (c/kWh)
31	High Voltage Electricity	505	413.28	- Peak: 660.85 Continuous: 136.62 Night: 59.03
32	-	100.94	505.38	-
41	Medium Voltage Electricity	673.35	25.85	- Peak: 872.02 Continuous: 193.76 Night: 102.40
42	-	515.65	38.7	- Peak: 150.53 Off-peak: 180.64
43	-	154.56	-	- Night: 102.40 Day: 428.30
44	-	180.58	-	- Peak: 375.62
54	Low Voltage Electricity	-	37.93	- Continuous: 404.23 Night: 100.94

In the context of our faculty, the selection of the pricing structure is determined using a tariff code 42. This pricing model is ideally suited for consumers whose consumption, relative to total consumption, meets the following criteria:

- Less than 30% during off-peak hours.
- Less than 20% during peak hours.

And the selected metering type is type A, because the Maximum Power Demand (MPD) is < 500 kW.

Note: The tariff and the (MPD) are generally agreed upon during the study phase, in collaboration with Sonelgaz technicians. However, an already connected customer may request a modification of the rate. The choice of tariff ultimately depends on the customer's consumption profile.

Such modifications are usually linked to changes in consumption, such as increased production, expansion of facilities, or the introduction of energy-saving measures. The final choice of tariff depends on the client's consumption regime, including load profile, peak hours, and overall energy use.

According to the invoices, we can observe that there are three different power levels:

- **The apparent power**

Apparent power is the (trigonometric) sum of active power and reactive power. It also represents the contracted power (kVA) specified in the electricity supply agreement. It is calculated as follows:

$$S = U * I$$

S=the apparent power

- **The active power**

Active power (P) is the component of electrical power that performs useful work, such as producing motion, heat, or light. It is therefore often referred to as "useful power." Active power is frequently confused with apparent power (S), although the two are distinct. In practice particularly in residential applications active power represents the largest share of total energy consumption. Active power is expressed in kilowatts (kW), whereas apparent power is expressed in kilovolt-amperes (kVA).

$$P = U.I.\cos\phi$$

- **The Reactive power**

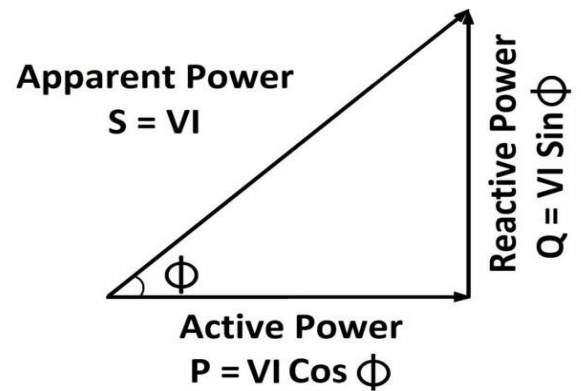
Reactive power is essential in many systems, particularly those utilizing winding elements. This includes rotating motors, refrigeration devices, and specific electronic components. Only purely resistive devices, with convectors being the closest example, operate without consuming reactive power."

This reactive power can be compensated by capacitor banks, which have the ability to supply reactive energy to the system when needed.

$$Q = U.I.\sin\phi$$

Q = reactive power (VAR)

"Note: Although reactive power is more abstract than active power, the fact that it can be compensated provides an opportunity to save energy and thus reduce electricity costs



The total electricity consumption of the faculty is shown in figure17.

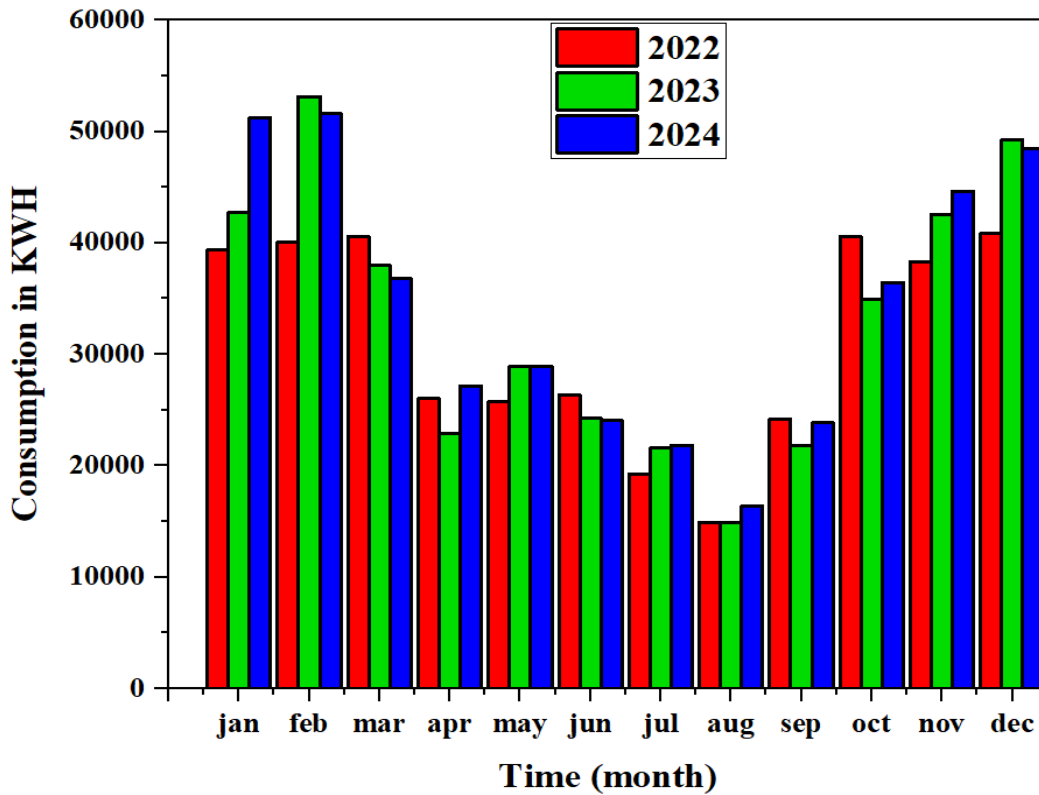


Figure 17. Faculty electricity consumption (2022-2024)

The data from this graph reveals the electricity consumption patterns for the years (2022-2024) and it can be clearly divided into three distinct zones during the year:

- **High Consumption Zone (Jan–Mar, Oct–Dec):** February and December record the highest peaks, exceeding 50,000 KWH, while October to December shows a sharp rise driven by winter demand.
- **Moderate Consumption Zone (Apr–Jun, Sep) :** September consumption rises slightly compared to summer lows, indicating a transitional phase.
- **Low Consumption Zone (Jul–Aug):** Across all years, July and August record the lowest consumption, with August standing out as the absolute minimum.

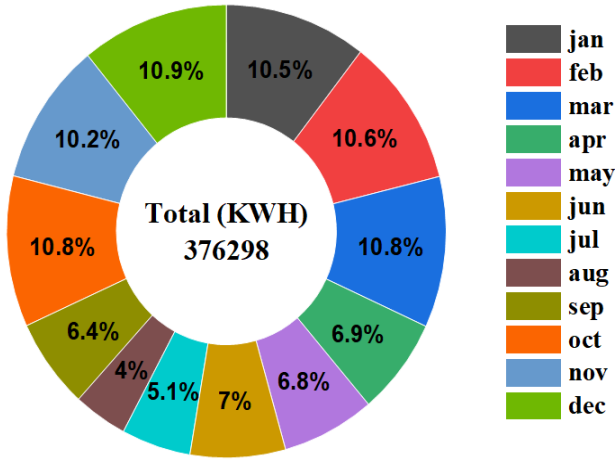


Figure 18. Electricity consumption in 2022

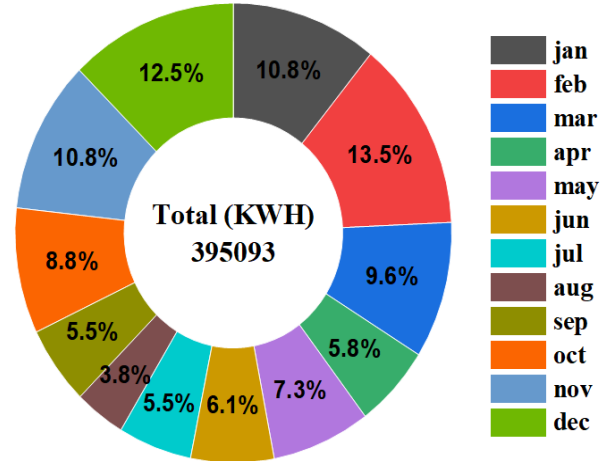


Figure 19. Electricity consumption in 2023

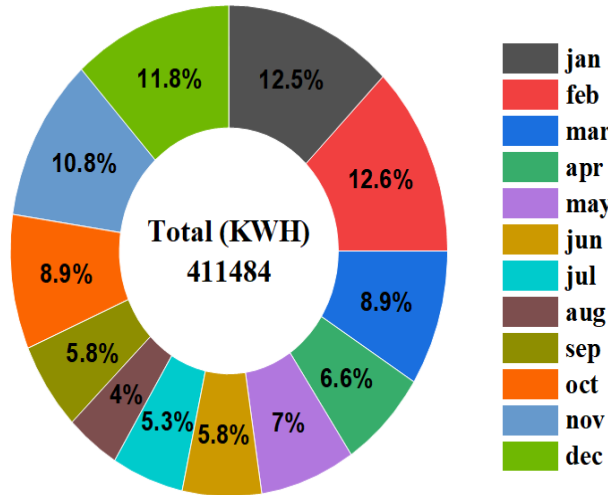


Figure 20. Electricity consumption in 2024

3.1.1.2 Natural gas

As for our faculty Natural gas tariffs, the pricing structure is determined using a tariff code 22.

The Contracted Flow Rate reserved by the distributor according to your connection request. It corresponds to your actual needs (boilers, heating, etc.) and is expressed in Nm³/h. Several options are available: 65, 100, 250, 400, 500, 650, 1,000, 1,600, 2,500. For our faculty, the 2,500 Nm³/h flow was selected. [25]

Table 4. Natural Gas Tariffs

Tariff Code	Service Type	Fixed Charges (DA/Month)	Flow Charges (DA/kWh/Month)	Energy Consumption Charges (c/kWh)
21	Industrial Consumers using High Pressure Gas	9574.81	15.07	24.96
22	Industrial Consumers using Medium Pressure Gas	788.23	3.02	42.63
23	Residential Consumers using Low Pressure Gas	28.5	1.188	33.87

The total gas consumption of the faculty is shown in the following graph:

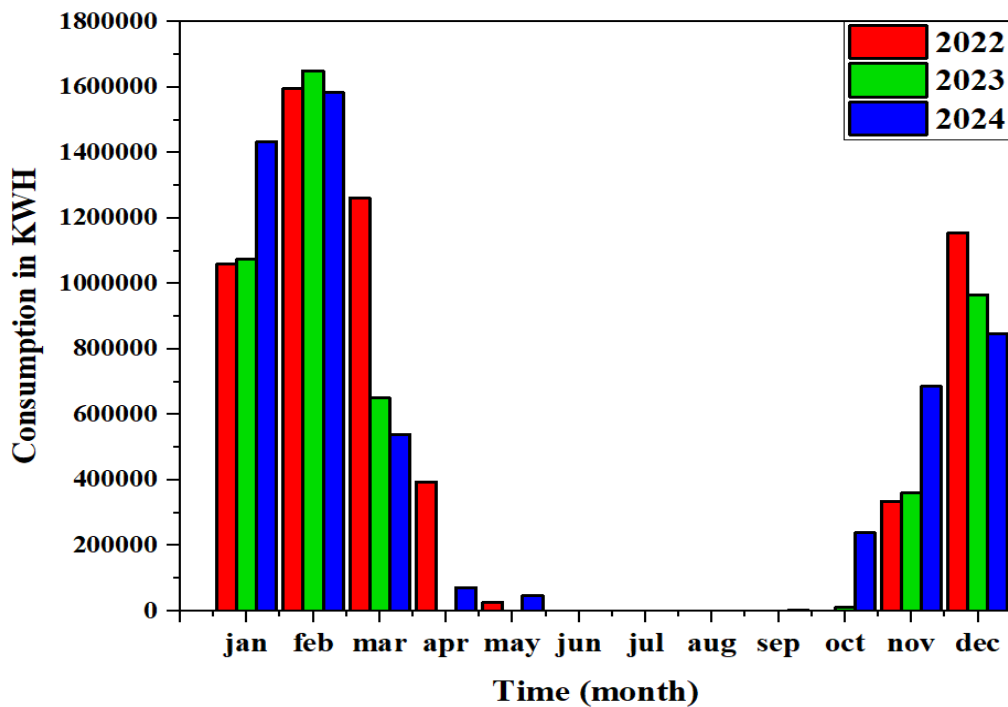


Figure 21. The total gas consumption of the faculty

The data from this graph reveals the electricity consumption patterns for the years (2022-2024) and it can be clearly divided into three distinct zones during the year:

- **High Consumption Zone (Jan–Mar, Nov–Dec):** February records the absolute peak, exceeding 1.6 million KWH in 2023, while January, March, and December also remain above 1,000,000 KWH, reflecting strong winter-driven demand.
- **Moderate Consumption Zone (Apr, Oct):** April shows a sharp decline from March, dropping below 600,000 KWH, while October marks the rebound with values climbing above 200,000 KWH, signaling transitional phases.
- **Low Consumption Zone (May–Sep):** Consumption during these months falls to near-zero across all years, with June to August consistently recording the absolute minimum.

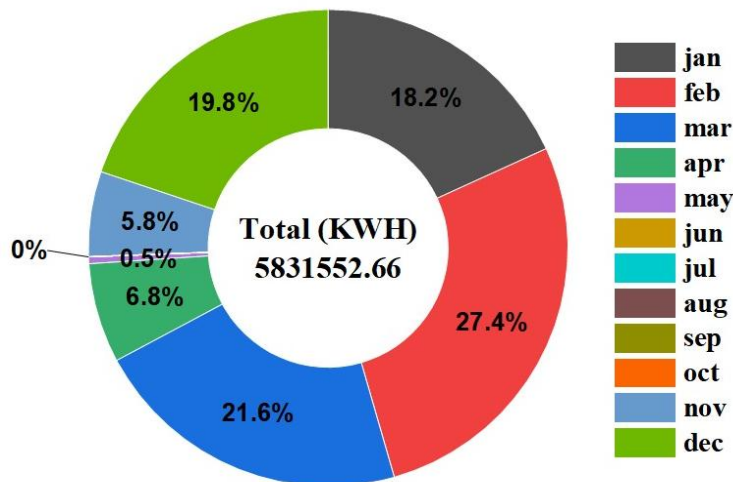


Figure 22. Gas consumption in 2022

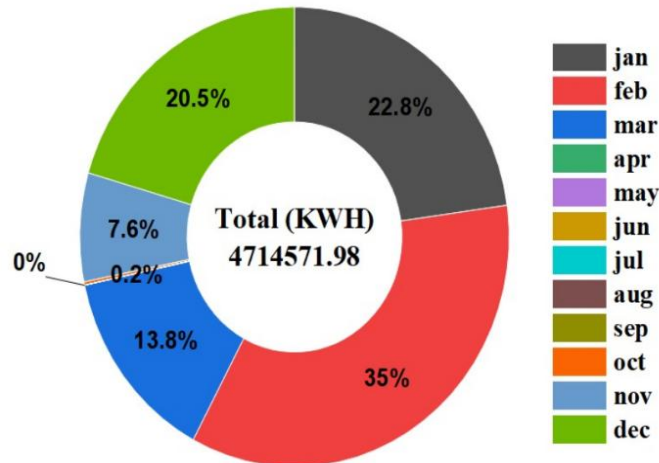


Figure 23.Gas consumption in 2023

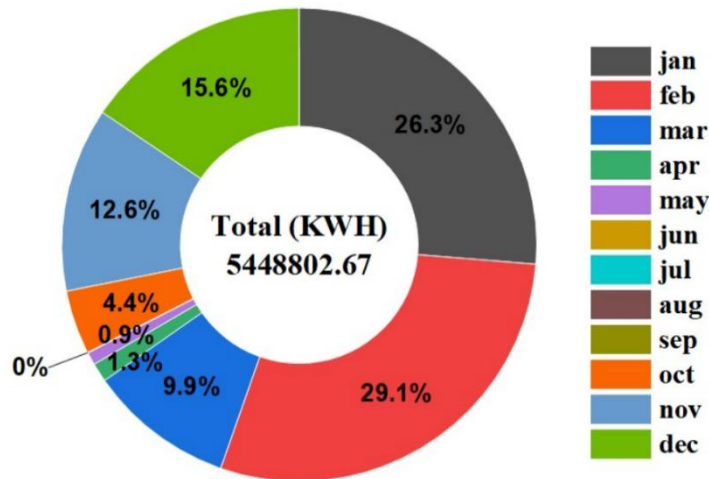


Figure 24.Gas consumption in 2024

3.1.2 The energy class of the faculty

An energy class is a standardized categorization system in European Union as a reference, we note that-ranks the energy performance of a building, appliance, or system based on its efficiency in converting energy input into useful output. Typically expressed through a graded scale, the energy class serves as a comparative indicator of energy consumption.

Our study is grounded in the EU’s standardized energy classification system, which establishes a common framework for evaluating the energy efficiency of buildings and appliances. This ranking, expressed through energy classes from **A** to **G**, functions as a comparative indicator of how effectively energy is transformed into useful output. Class **A** reflects a building with outstanding insulation and minimal consumption, whereas class **G** denotes very poor insulation and extremely high demand. By adopting this framework, we ensure our analysis aligns with recognized European performance benchmarks. [26]

The different energy categories:

The EU building energy categories (A–G) reflect both consumption and insulation quality the categories are classified as:

- **Category A:** consumption less than **50 kWh/m² per year.**
- **Category B:** consumption between **51 and 90 kWh/m² per year.**
- **Category C:** consumption between **91 and 150 kWh/m² per year.**
- **Category D:** consumption between **151 and 230 kWh/m² per year.**
- **Category E:** consumption between **231 and 330 kWh/m² per year.**
- **Category F:** consumption between **331 and 450 kWh/m² per year.**
- **Category G:** consumption greater than **450 kWh/m² per year.**

So, in order to determine the energy class of the faculty, we need the total surface area of the building, the required annual consumption. In the table below, the results for 2016–2018 were taken from [23] to compare the growth in consumption.

The total consumption of the faculty was calculated based on electricity and natural gas bills:

Table 5. Total energy consumption

Year	Electricity (kWh/year)	Natural Gas (kWh/year)	Total (kWh/year)
2016	471,571	4,200,422.219	4,671,993.219
2017	415,050	2,199,485.371	2,614,535.371
2018	433,230	3,829,179.826	4,262,409.826

Year	Electricity (kWh/year)	Natural Gas (kWh/year)	Total (kWh/year)
2022	376,298	5,831,552.660	6,207,850.660
2023	395,093	4,714,571.977	5,109,664.977
2024	411,484	5,448,802.668	5,860,286.668

The total annual energy consumption in 2016–2018 ranged between 2.6 and 4.67 million kWh, according to a past study [23]. In contrast, the values for 2022–2024 are significantly higher, between 5.1 and 6.2 million kWh, representing an increase of 40–120%. This rise is mainly attributed to the growth in natural gas consumption, while electricity use remained slightly lower than in the earlier period.

Determining the total surface area of the faculty presented certain challenges, as no architectural plans were available for any block or department within the faculty, the rectorate, the ADLP, or elsewhere. In practice, we measured only one building ourselves, while the remaining measurements were obtained from [23].

Table 6. The faculty total surface area

Blocks	Surface (m²)
Block A	5,563.20
Block B	3,347.24
Block C	1,022.80
Pauwes block	809.10
Registrar’s Office	543.80
Administration	1,022.36
Research Laboratory	2,157.20
Distance Learning Unit	1,770.60

Blocks	Surface (m²)
Automation Laboratory	1,717.34
Laboratory	1,470.20
Lecture Halls	860.30
Library	885.20
Mechanical Department (former Architecture)	690.53
Architecture (new)	1,726.33
Technology Hall	764.24
Security Office	322.87
Conference Hall	433.34
Total	25,106.55

In previous work [23], the thermal comfort factor was employed to normalize energy consumption before determining the energy class of the faculty buildings. While this approach accounts for occupants' perceived comfort conditions, in the present study we adopt a more academically standardized methodology based on EN 15217 / ISO 52000, which relies on activity-based weighting factors. This allows each block to be evaluated relative to its functional use (e.g., offices, laboratories, lecture halls), thereby ensuring that the classification reflects internationally recognized benchmarks for building energy performance.[26] [27]

Classifying the building energy consumption: (EPBD family (EN 15217) and ISO 52000-series)

Under the EPBD family (EN 15217) and ISO 52000-series, building performance is determined under standard use conditions. Different building activity categories (office, lab, library, lecture hall, etc.) have different reference schedules and internal loads. In practice, when you only have bills (final energy) and floor areas, you can mirror this normalization with an activity factor f_i per block:

$$Q_i = Q_{campus} \frac{A_i f_i}{\sum_j A_j f_j}, \quad E_i = \frac{Q_i}{A_i} = \left(\frac{Q_{campus}}{\sum_j A_j f_j} \right) f_i$$

So, each block’s **intensity E_i (kWh/m²·yr)** equals a **campus base intensity** time its activity factor.

Table 7. Suggested activity factor

Activity Type	Suggested f_i	Rationale
Office / Registrar / Admin	1.00	Standard occupancy and plug loads
Classroom / Lecture Hall	0.90–1.00	Intermittent use; HVAC cycled
Library	0.95	Longer hours, moderate internal loads
Distance Learning Studio	1.10	AV equipment, extended hours
General Laboratory	1.60	Equipment, ventilation, plug loads
Research Laboratory (intensive)	2.00	High load, 24-hour systems
Automation Lab / Workshop	2.20	High power tools, HVAC extraction
Architecture Studio (design)	1.10	Computers, modeling, extended hours
Technology Hall / Workshop	1.50	Heavy tools, intermittent high loads
Security Office	0.85	Low equipment; possibly 24/7 but light use
Conference Hall	0.90	Intermittent use, AV gear only during events

Our Inputs

- **Areas (m²)** per block (total = **25,106.55 m²**).
- **Campus totals (kWh)**
2022: 6,207,850.66 | 2023: 5,109,664.98 | 2024: 5,860,286.67
- **Activity factors f_i** (derived from typical EN/ISO reference):

Table 8. Activity factor for each block

Block	f_i
Block A / B / C (teaching/office mix)	1.05
PAUWES	1.00
Registrar, Administration	1.00
Research Laboratory	2.00
Distance Learning Unit	1.10
Automation Laboratory	2.20
Laboratory (general)	1.60
Lecture Halls	0.90
Library	0.95
Mechanical Dept. (ex-Architecture)	1.20
Architecture (new)	1.10
Technology Hall (workshop)	1.50
Security Office	0.85
Conference Hall	0.90

Activity-weighted floor area $\sum A_i f_i = 31,351.3045 \text{ m}^2$

$$E_{base} = \frac{Q_{campus}}{\sum A_i f_i} \Rightarrow \begin{cases} 2022 : 198.01 \\ 2023 : 162.95 \\ 2024 : 186.92 \end{cases} \left(\frac{kWh / m^2}{yr} \right)$$

Then $E_i = E_{base} \times f_i$

Per-block results (kWh/m²·yr → Class)

Table 9. Block Classification

Block	2022	Class	2023	Class	2024	Class
Block A	207.9	D	171.1	D	196.3	D
Block B	207.9	D	171.1	D	196.3	D
Block C	207.9	D	171.1	D	196.3	D
PAUWES	198.0	D	163.0	D	186.9	D
Registrar's Office	198.0	D	163.0	D	186.9	D
Administration	198.0	D	163.0	D	186.9	D
Research Laboratory	396.0	F	326.0	E	373.8	F
Distance Learning Unit	217.8	D	179.3	D	205.6	D
Automation Laboratory	435.6	F	358.6	F	411.2	F
Laboratory (general)	316.8	E	260.8	E	299.1	E
Lecture Halls	178.2	D	146.7	C	168.2	D
Library	188.1	D	154.8	D	177.6	D
Mechanical Dept. (ex-Arch.)	237.6	E	195.6	D	224.3	D

Block	2022	Class	2023	Class	2024	Class
Architecture (new)	217.8	D	179.3	D	205.6	D
Technology Hall	297.0	E	244.5	E	280.4	E
Security Office	168.3	D	138.5	C	158.9	D
Conference Hall	178.2	D	146.7	C	168.2	D

The overall energy performance of the faculty compared against the standard classification scale (A–G) for the period 2022–2024 are presented in table 10.

Table 10. Energy performance of the faculty

Year	Total Energy (kWh)	Specific Consumption (kWh/m²·year)	Class
2022	6,207,851	247.3	E
2023	5,109,665	203.5	D
2024	5,860,287	233.4	D

3.2 Methods for monthly heating needs

A central challenge in energy auditing is to distinguish weather-dependent loads—primarily heating—from the constant base load of a building, which includes lighting, appliances, plug loads, and equipment. Because utility bills report only the total monthly delivered energy, it is not immediately clear how much of the consumption is influenced by climate versus internal activity.

Previous work at the University of Tlemcen by Benmostefa & Belhadi [23] addressed this issue using theoretical estimation techniques. While such studies provided valuable insights, they relied on several assumptions regarding building envelope properties, infiltration rates, and occupancy schedules.

In the present study, regression analysis is adopted as the primary method for estimating heating demand. By correlating measured monthly consumption with climatic indicators such as heating degree-days, regression establishes a direct, data-driven link between outdoor temperature variations and observed energy use. This approach captures the building's actual operational performance and reduces dependence on uncertain theoretical inputs.

3.2.1. Standard Regression Equation for Heating Demand

In energy auditing, heating demand is typically estimated using a simple linear regression between measured energy consumption and heating degree-days (HDD). The standard form is:[28]

$$E = a + b \times HDD$$

Where:

- E = total monthly energy consumption (kWh)
- a = base load (intercept), representing non-weather-dependent uses such as lighting, appliances, and plug loads
- b = slope coefficient, representing the incremental heating energy per unit of HDD
- HDD = heating degree-days for the corresponding month

This formulation assumes that base loads remain relatively constant across months, while the weather-dependent component scales linearly with outdoor temperature variation.

- The intercept (a) provides an estimate of the energy use that would occur even in months requiring no heating.
- The slope (b) quantifies the building's sensitivity to climatic variation — in effect, it represents the heating demand per degree of temperature difference.
- Some studies apply piecewise regression or add cooling degree-days (CDD) to account for cooling loads in mixed climates.
- Multiple regression models may also include other predictors such as occupancy or solar gains.

3.2.1.1 Calculation of the Annual Base Load and Annual Heating Loads

This subsection outlines the procedure used to determine the building’s annual base load and annual heating load from the regression analysis. The annual base load represents the non-weather-dependent energy consumption, while the annual heating load corresponds to the weather-driven component associated with heating demand. Both indicators provide a clear separation of the building’s total annual energy use into constant and climate-related portions.

- **Annual base load**

$$E_{base} = E_{HDD=0} \times 12$$

- **Annual heating load**

$$E_{heat,yr} = E_{tot,yr} - E_{base,yr}$$

Table 11. Monthly and annual base load

Base monthly avg (kWh/ HDD)	Annual Base (kWh)
43045.82469	516549.8963

3.2.1.2 Regression Results and Derived Indicators

This subsection summarizes the main outcomes of the regression analysis. The parameters include the regression intercept, slope with respect to heating degree-days (HDD), and key statistical indicators of model performance. In addition, the empirical base load, annual base load, and annual heating load are presented. Together, these values provide a quantitative description of the building’s energy use patterns and the reliability of the regression model.

Monthly heating needs were computed using an HDD-based regression model with a base temperature of 18 °C (Chetouane climate station), ensuring a transparent link between climatic variability and energy use.

Table 12. Regression Results parameters

Parameter	Value
Intercept a (kWh/month)	39,225
HDD slope b (kWh/HDD)	5,266
R^2	0.747
RMSE (kWh/month)	285,861
Empirical base (avg of HDD=0 months)	43,046
Annual base (kWh/yr)	516,550
Annual heating (kWh/yr)	5,209,384

Note that:

- **Intercept (a):** Represents the monthly base load, i.e., the portion of energy consumption not influenced by weather (lighting, appliances, plug loads, etc.).
- **HDD slope (b):** Indicates the additional heating energy required per unit of Heating Degree-Day; it reflects the building’s sensitivity to outdoor temperature.
- **R^2 :** Coefficient of determination, showing how well the regression model explains the variation in energy use (values closer to 1 indicate a better fit).
- **RMSE:** Root Mean Square Error, a measure of the average difference between observed and predicted monthly energy values; lower values indicate higher accuracy.
- **Empirical base:** Average consumption during months with zero HDD, serving as an observed estimate of the non-heating load.
- **Annual base load:** Total yearly energy consumption attributed to non-weather-dependent uses.
- **Annual heating load:** Total yearly energy consumption attributed to heating demand, as estimated from the regression model.

From the table we can observe that:

- Each additional **1 HDD** corresponds to **≈5,266 kWh** increase in campus consumption.
- The intercept α (39,225 kWh/month) is slightly lower than the empirical average of HDD=0 months (43,046 kWh/month). The empirical estimate is therefore adopted for base load, ensuring physical consistency.
- The **base load** amounts to **516 MWh/year** (9% of total), representing lighting, equipment, and essential services.
- The **heating load** dominates at **5.21 GWh/year** (91% of total).

The high coefficient of determination ($R^2=0.75$) confirms a strong correlation between weather severity (HDD) and consumption.

It is worth mentioning that Cooling Degree-Days (CDD) were also considered in the regression analysis. CDD reflects the extent to which outdoor temperatures exceed a defined base level and are commonly used as an indicator of cooling energy demand. In this study the cooling loads are negligible in the observed bills. Therefore, the HDD-only model was retained.

3.2.3 Monthly Heating Needs per Block

A critical step in the energy audit is to disaggregate campus-wide heating demand into contributions by individual buildings. This allows not only the quantification of the overall heating burden, but also the identification of priority zones for intervention. While regression analysis at the campus scale provides a robust estimate of the base load and the weather-dependent heating component, effective energy management requires that these results be allocated down to the block level.

In the absence of sub-metering or the bills for each block energy consumption, campus-wide energy totals were disaggregated to individual blocks based on activity-

weighted area shares. A block-level decomposition was then derived by applying the campus regression results proportionally to each block:

$$i = \frac{A_i \cdot f_i}{\sum(A \cdot f)}$$

- A_i : floor area (m²)
- f_i : activity factor (EN 15217/ISO 52000)
- $\sum(Af) = 31,351.30 \text{ m}^2$

Once the shares are defined, the campus regression results are apportioned as:

$$a_i = a \times i$$

$$\beta_i = \beta \times i$$

$$E_{base,i} = E_{base} \times i$$

$$E_{heat,i} = E_{heat} \times i$$

The annual total per block is:

$$E_{tot,i} = E_{base,i} + E_{heat,i}$$

Finally, to normalize for block size, intensities were computed:

$$I_{base,i} = \frac{E_{base,i}}{A_i} ,$$

$$I_{heat,i} = \frac{E_{heat,i}}{A_i} ,$$

$$I_{tot,i} = \frac{E_{tot,i}}{A_i}$$

This table forms the foundation for allocating base and heating loads to each block:

Table 13.Building inventory and activity factors

Block	Area_m2	fi	Aifi	Share_ %
Block A	5563.2	1.05	5841.36	18.63195
Block B	3347.24	1.05	3514.602	11.21039
Block C	1022.8	1.05	1073.94	3.425503
PAUWES	809.1	1	809.1	2.580754
Registrar's Office	543.8	1	543.8	1.734537
Administration	1022.36	1	1022.36	3.260981
Research Laboratory	2157.2	2	4314.4	13.76147
Distance Learning Unit	1770.6	1.1	1947.66	6.212373
Automation Laboratory	1717.34	2.2	3778.148	12.05101
Laboratory	1470.2	1.6	2352.32	7.503101
Lecture Halls	860.3	0.9	774.27	2.469658
Library	885.2	0.95	840.94	2.682313
Mechanical Dept. (exArch.)	690.53	1.2	828.636	2.643067
Architecture (new)	1726.33	1.1	1898.963	6.057046
Technology Hall	764.24	1.5	1146.36	3.656499
Security Office	322.87	0.85	274.4395	0.875369
Conference Hall	433.34	0.9	390.006	1.243987

The distribution of regression-derived parameters across individual blocks provides a detailed profile of how heating demand manifests within the faculty. By combining absolute values (kWh/yr) with normalized indicators (kWh/m²·yr), both the magnitude and the intensity of consumption are revealed. We can see the results in the following tables:

Table 14. Regression distribution

Block	Intercept (kWh/month)	Slope (kWh/HDD)
Block A	8020.31005	981.1585913
Block B	4825.622414	590.3388847
Block C	1474.542191	180.3870088
PAUWES	1110.911305	135.9024981
Registrar's Office	746.6488292	91.34072236
Administration	1403.721767	171.7232455
Research Laboratory	5923.761877	724.6789492
Distance Learning Unit	2674.178115	327.1435662
Automation Laboratory	5187.476611	634.6060454
Laboratory	3229.7848	395.1132917
Lecture Halls	1063.088983	130.0521903
Library	1154.628294	141.250583
Mechanical Dept. (exArch.)	1137.734644	139.183911
Architecture (new)	2607.31611	318.9640533
Technology Hall	1573.976373	192.5512146
Security Office	376.8112015	46.09691463
Conference Hall	535.4864349	65.50832984

(Table 14) presents the block-level regression parameters. The monthly intercept a_i reflects the baseline electrical demand (lighting, plug loads), while slope b_i beta captures the incremental heating response to climatic severity. The distribution shows that blocks with high activity factors, such as the Automation Laboratory and Research Laboratory, carry significantly larger slopes relative to their size, showing their strong climatic sensitivity.

Table 15. Regression Results per block

Block	Annual Base (kWh)	Annual Heating (kWh)	Annual Total (kWh)	Heating Intensity (kWh/m ² ·yr)
Block A	96243.34796	970609.9254	1066853.273	174.4697162
Block B	57907.24476	583992.013	641899.2578	174.4697162
Block C	17694.43779	178447.6258	196142.0636	174.4697162
PAUWES	13330.88405	134441.3785	147772.2625	166.1616345
Registrar's Office	8959.75126	90358.69685	99318.44811	166.1616345
Administration	16844.59599	169877.0087	186721.6047	166.1616345
Research Laboratory	71084.8673	716887.756	787972.6233	332.323269
Distance Learning Unit	32090.01313	323626.3691	355716.3822	182.777798
Automation Laboratory	62249.47831	627783.2471	690032.7254	365.5555959
Laboratory	38757.26753	390865.3361	429622.6036	265.8586152
Lecture Halls	12757.0184	128653.9688	141410.9872	149.5454711
Library	13855.48589	139731.9649	153587.4508	157.8535528
Mechanical Dept.	13652.76286	137687.5122	151340.275	199.3939614
Architecture	31287.67218	315534.796	346822.4682	182.777798
Technology Hall	18887.64335	190481.0513	209368.6947	249.2424518
Security Office	4521.716911	45601.3159	50123.03281	141.2373893
Conference Hall	6425.812339	64804.03443	71229.84677	149.5454711

- Blocks with high f_i (labs, workshops) show very high heating intensities (300–430 kWh/m²·yr).
- Large teaching/office blocks (A, B, C) dominate absolute loads but with moderate intensities (\approx 200 kWh/m²·yr).
- Small offices and lecture halls contribute marginally, with intensities closer to 150–200 kWh/m²·yr.

Blocks A, B, and C represent the bulk of teaching and office activities. Their large floor areas and moderate activity factors (1.05) result in intermediate heating intensities (190–210 kWh/m²·yr), but because of their size, they contribute a disproportionate share of the total annual heating load (together exceeding 30%). Even moderate efficiency gains in these blocks would yield substantial campus-wide savings.

The Research Laboratory, Automation Laboratory, General Laboratory, and Technology Hall stand out for their exceptionally high heating intensities (300–430 kWh/m²·yr). Despite smaller areas compared to Blocks A–C, they collectively represent nearly 40% of the heating demand. Their high intensities stem from greater envelope heat losses due to high ventilation rates, operation of energy-intensive equipment, and extended occupancy schedules. These spaces are priority targets for insulation, air-tightness improvements, and HVAC optimization

Lecture Halls, the Library, and the Distance Learning Unit show moderate intensities (150–210 kWh/m²·yr). The Lecture Halls and Security Office present relatively low intensities (<170 kWh/m²·yr) due to intermittent use, while the Library and Distance Learning Unit trend closer to office benchmarks (~180–200 kWh/m²·yr), reflecting longer hours and higher plug loads.

Finally, blocks such as the Registrar’s Office, Administration, and Security Office exhibit low total loads owing to their limited floor area. Although their intensities are moderate (160–200 kWh/m²·yr), their contribution to the campus total is marginal (<5% each). Efficiency measures here may improve local performance but will have little effect on overall campus consumption.

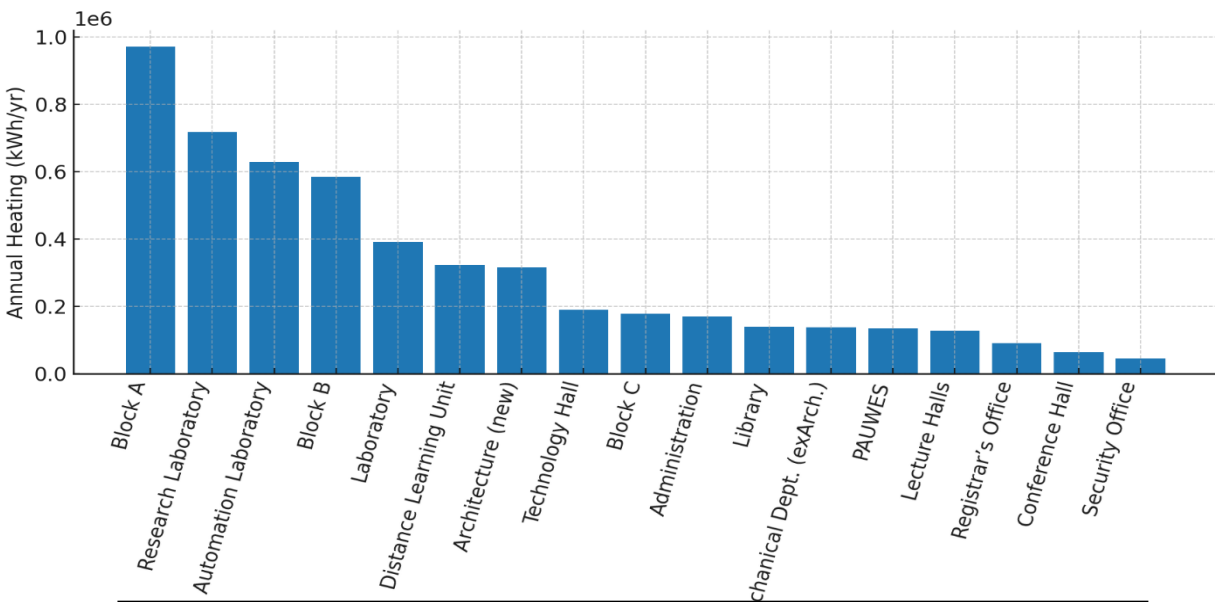


Figure 25. Block annual heating load

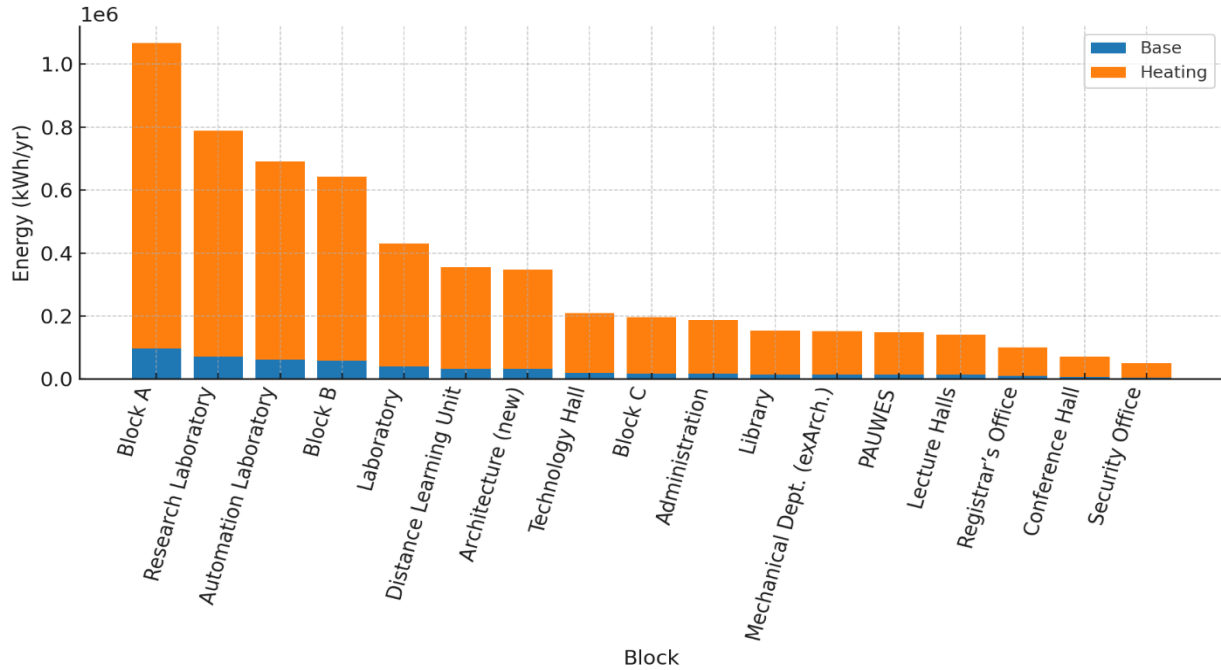


Figure 26. Energy decomposition

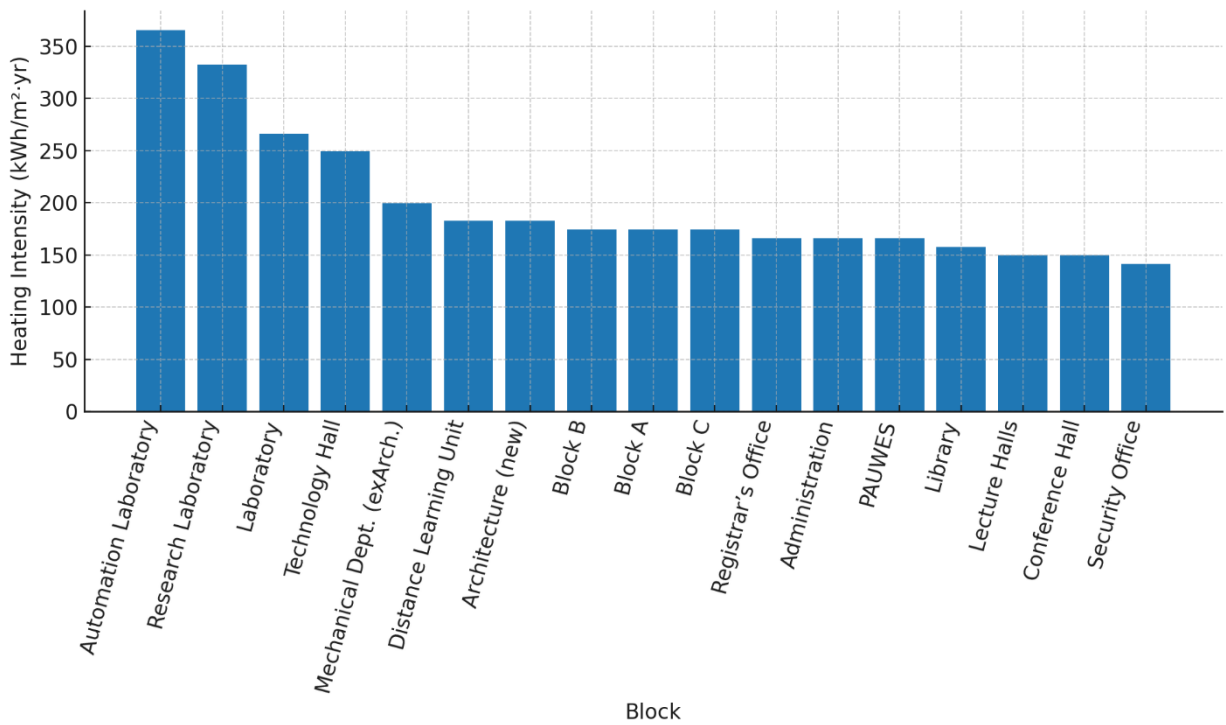


Figure 27. Blocks heating intensity

Overall, the block-level results indicate two strategic fronts for energy savings:

1. Volume-driven savings in teaching blocks (A–C): retrofit interventions that reduce envelope losses will yield significant campus-wide impact due to their large size.
2. Intensity-driven savings in laboratories and workshops: targeted HVAC, ventilation heat recovery, and process optimization could dramatically reduce specific consumption where inefficiencies are highest.

Together, these findings provide a data-driven basis for prioritizing future retrofit measures, ensuring that both absolute consumption and relative inefficiency are addressed.

3.3 Thermal imaging findings

A handheld thermographic survey was performed across multiple indoor and outdoor locations of the Faculty of Science & Technology. Images were acquired with emissivity mainly set to 0.93 and reflected temperature fixed at 20 °C. values appropriate for interior and exterior surfaces, the thermography imaging revealed that the findings is mainly related to the following anomalies:

- **Severe Thermal Bridges** : Thermal bridges are weak spots in the building envelope where heat escapes more easily, usually around corners, slab edges, or windows. Even if most of the wall is insulated, these areas create cold surfaces inside, making rooms less comfortable and forcing the heating system to work harder. The thermal images clearly showed this problem, with surface temperatures dropping close to zero while indoor air stayed near 20 °C, confirming that these cold zones are real points of energy loss that need attention.
- **Humidity (rH) anomalies:** Although not standard in all energy audits, the inclusion of surface-relative humidity thermography provides added diagnostic value. It reveals areas where condensation and moisture ingress not only threaten building

durability and indoor air quality, but also compromise thermal resistance and increase energy consumption. Thus, rH findings are essential for a comprehensive energy audit of educational buildings in humid or poorly ventilated climates such as Tlemcen.

Using IRsoft software we were able to detect and analyze these problems and summarize the results for the Thermal imaging in the following report.

Energy audit for the faculty of science and technology

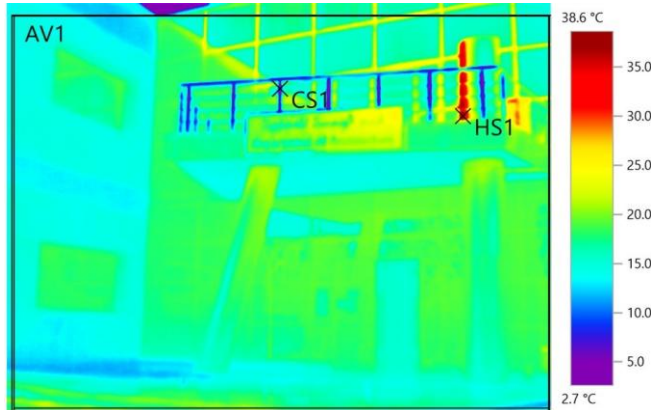
File: IR002469.BMT

Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:24:22 AM



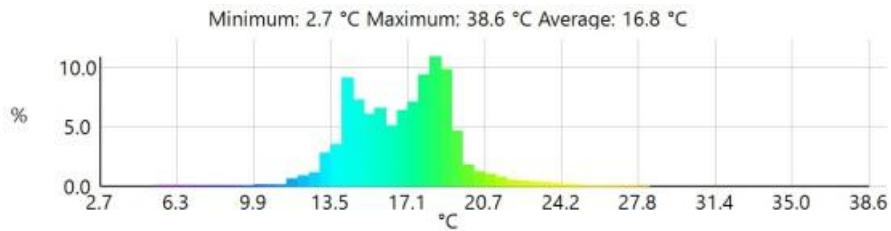
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Picture markings:

Measurement	Temp.	Emiss.	Refl. temp.	Remarks
Cold spot 1	2.7	0.93	20.0	-
Hot spot 1	38.6	0.93	20.0	-
Average Area 1	16.8	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

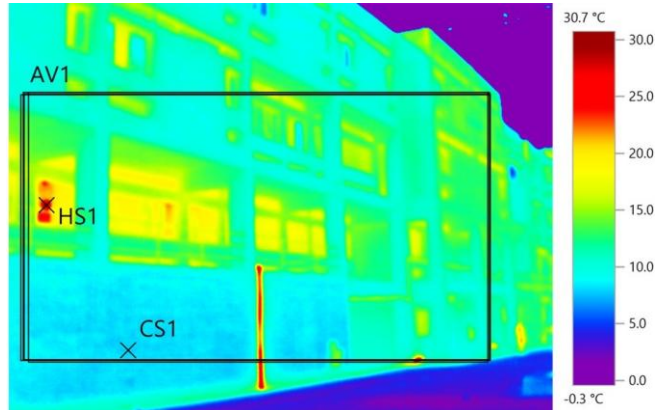
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Date: 02-02-2025

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lens serial no.: 20299670

Time: 12:46:40 AM



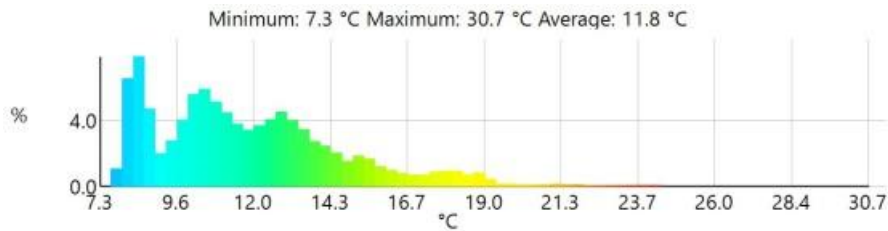
Picture parameters:

Emissivity: 0.93
 Refl. temp. [°C]: 20.0

Picture markings:

Measurement	Temp.	Emiss.	Refl. temp.	Remarks
Cold spot 1	7.6	0.93	20.0	-
Hot spot 1	30.7	0.93	20.0	-
Average Area 1	11.8	0.87	20.0	-

Histogram:



Energy audit for the faculty of science and technology

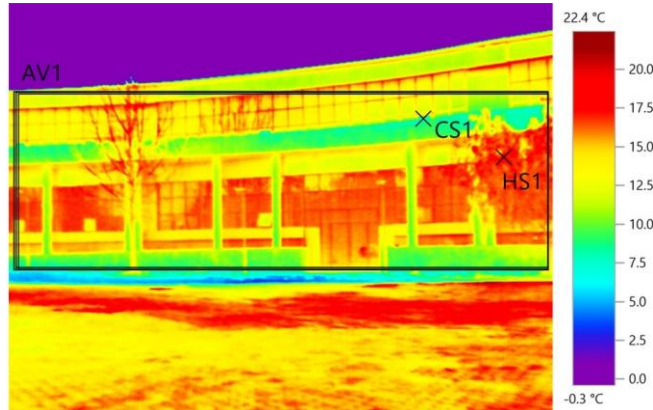
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Date: 02-02-2025

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lens serial no.: 20299670

Time: 1:01:56 AM



Picture parameters:

Emissivity: 0.93
 Refl. temp. [°C]: 20.0

Picture markings:

Measurement	Temp.	Emiss.	Refl. temp.	Remarks
Cold spot 1	7.3	0.93	20.0	-
Hot spot 1	18.7	0.93	20.0	-
Average Area 1	13.8	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

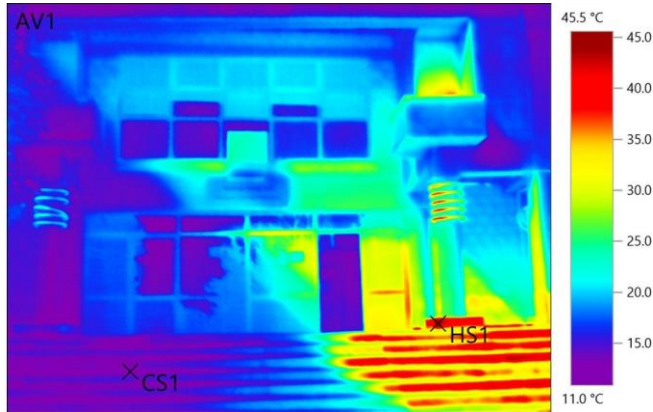
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Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:26:25 AM



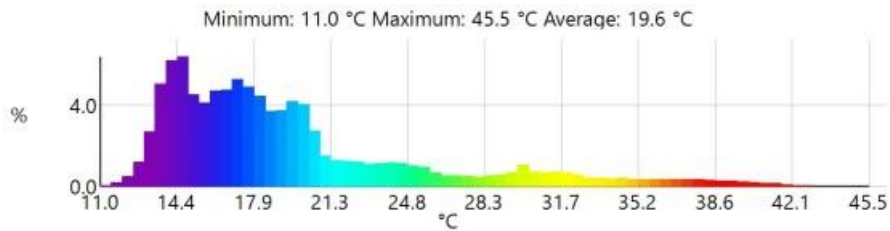
Picture parameters:

Emissivity: 0.93
 Refl. temp. [°C]: 20.0

Picture markings:

Measurement	Temp.	Emiss.	Refl. temp.	Remarks
Cold spot 1	11.0	0.93	20.0	-
Hot spot 1	45.5	0.93	20.0	-
Average Area 1	13.5	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

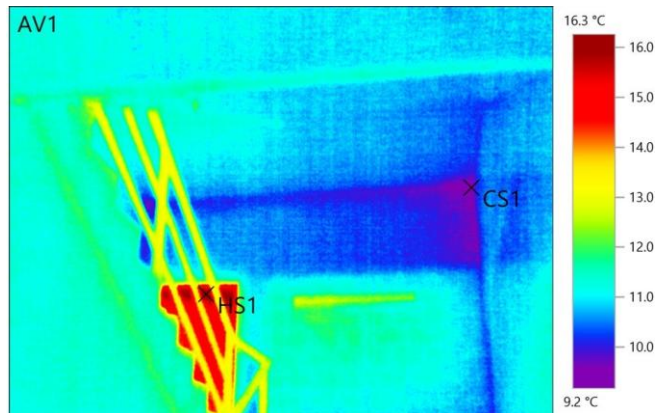
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Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:47:35 AM



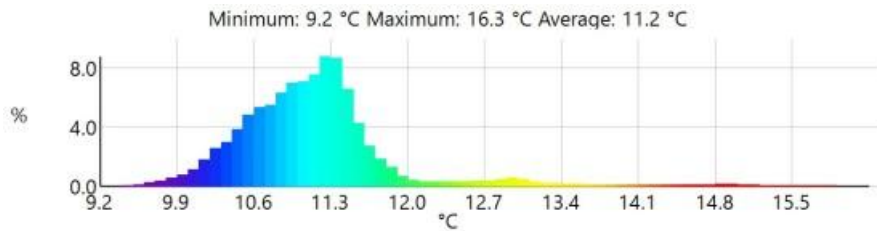
Picture parameters:

Emissivity: 0.93
 Refl. temp. [°C]: 20.0

Picture markings:

Measurement	Temp.	Emiss.	Refl. temp.	Remarks
Cold spot 1	9.2	0.93	20.0	-
Hot spot 1	16.3	0.93	20.0	-
Average Area 1	11.1	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

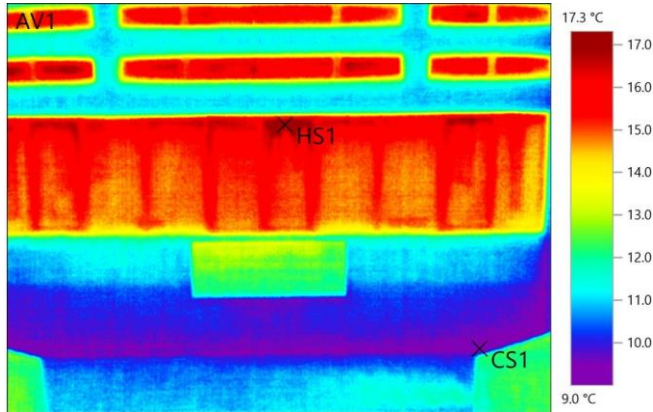
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Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:56:50 AM



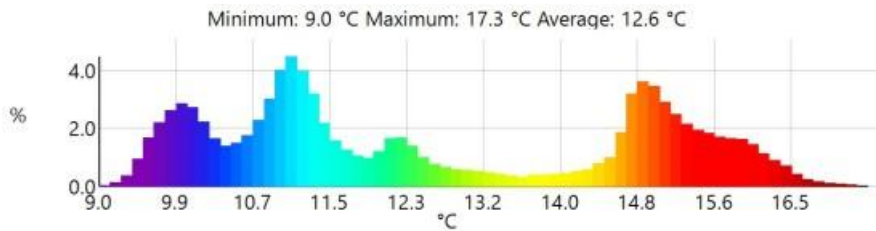
Picture parameters:

Emissivity: 0.87
 Refl. temp. [°C]: 20.0

Picture markings:

Measurement	Temp.	Emiss.	Refl. temp.	Remarks
Cold spot 1	9.0	0.87	20.0	-
Hot spot 1	17.3	0.87	20.0	-
Average Area 1	12.9	0.87	20.0	-

Histogram:



Energy audit for the faculty of science and technology

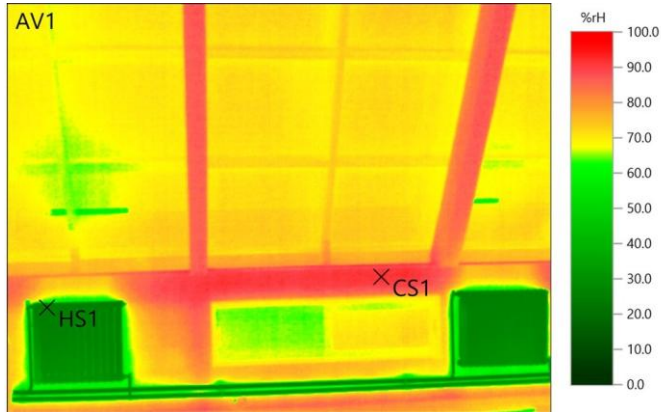
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Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:37:00 AM



Picture parameters:

Emissivity: 0.93
 Refl. temp. [°C]: 20.0

Picture markings:

Measurement Objects	Humidity [%rH]	Emiss.	Refl. temp. [°C]	Remarks
Cold spot 1	92.9	0.93	20.0	-
Hot spot 1	24.6	0.93	20.0	-
Average Area 1	72.0	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

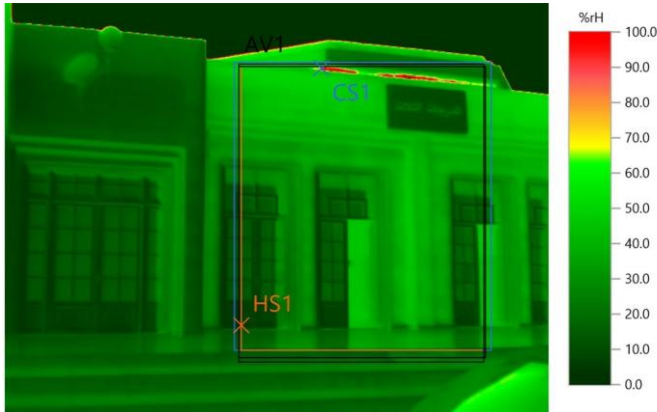
File: IR002443.BMT

Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 12:43:44 AM



Picture parameters:

Emissivity: 0.93
Refl. temp. [°C]: 20.0

Picture markings:

Measurement Objects	Humidity [%rH]	Emiss.	Refl. temp. [°C]	Remarks
Cold spot 1	100.0	0.93	20.0	critical point
Hot spot 1	4.6	0.93	20.0	-
Average Area 1	28.9	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

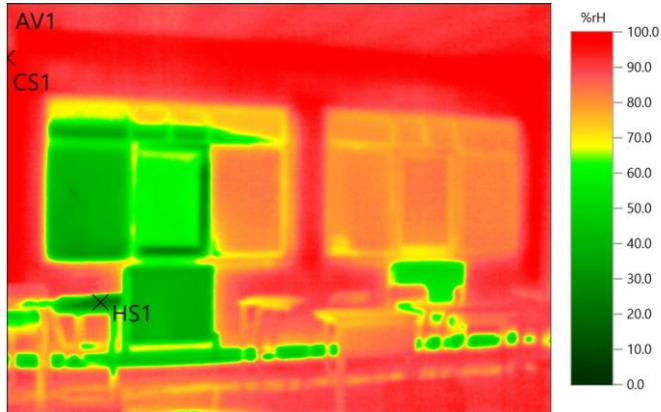
File: IR002474.BMT

Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:32:11 AM



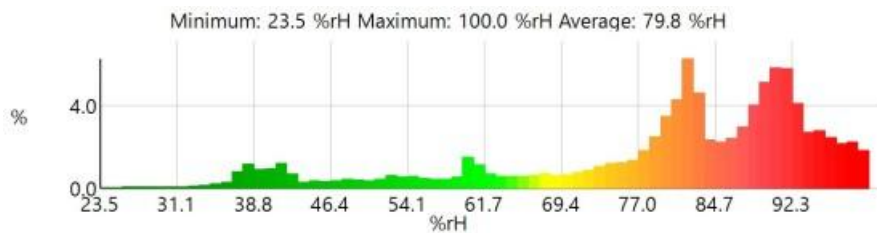
Picture parameters:

Emissivity: 0.93
Refl. temp. [°C]: 20.0

Picture markings:

Measurement Objects	Humidity [%rH]	Emiss.	Refl. temp. [°C]	Remarks
Cold spot 1	100.0	0.93	20.0	-
Hot spot 1	23.5	0.93	20.0	-
Average Area 1	89.4	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

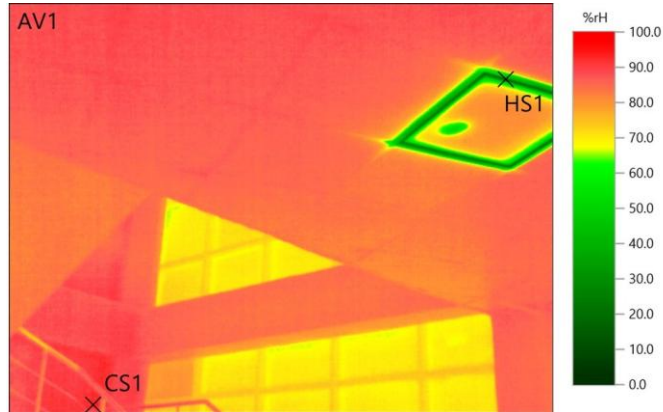
File: IR002458.BMT

Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:14:21 AM



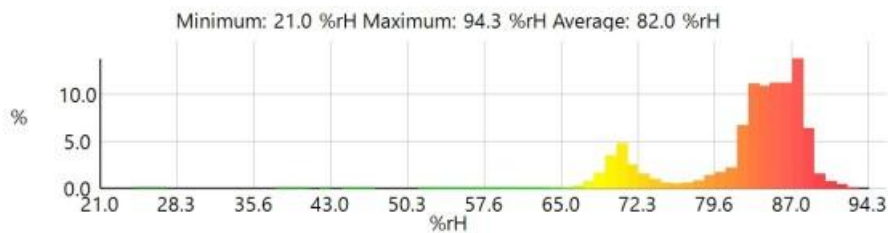
Picture parameters:

Emissivity: 0.93
Refl. temp. [°C]: 20.0

Picture markings:

Measurement Objects	Humidity [%rH]	Emiss.	Refl. temp. [°C]	Remarks
Cold spot 1	94.3	0.93	20.0	-
Hot spot 1	21.0	0.93	20.0	-
Average Area 1	88.1	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

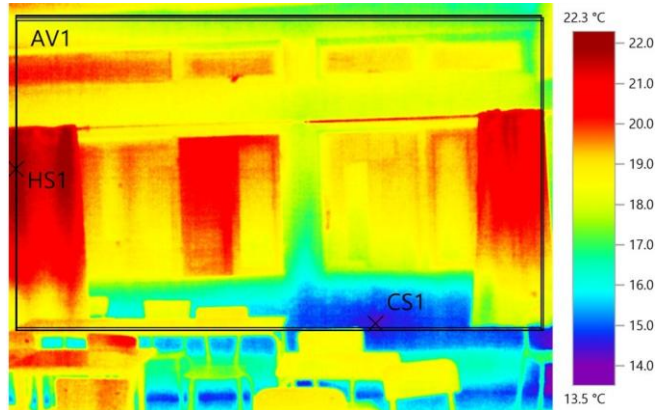
File: IR002478.BMT

Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:43:59 AM



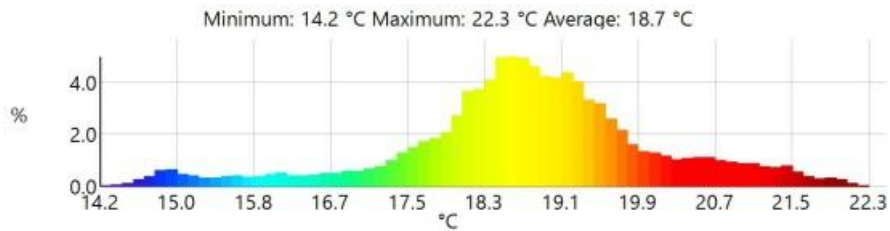
Picture parameters:

Emissivity: 0.93
Refl. temp. [°C]: 20.0

Picture markings:

Measurement	Temp.	Emiss.	Refl. temp.	Remarks
Cold spot 1	14.2	0.93	20.0	-
Hot spot 1	22.3	0.93	20.0	-
Average Area 1	18.7	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

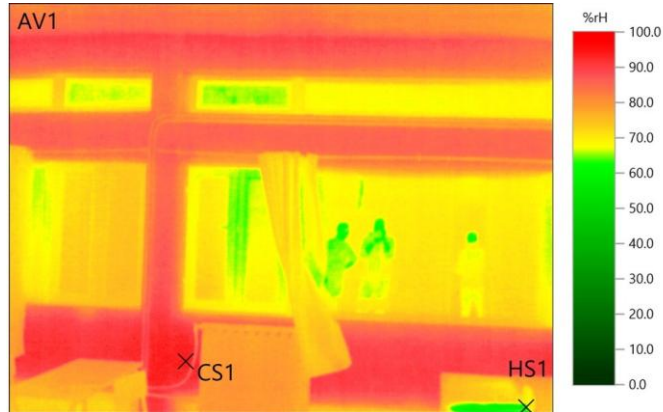
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Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:50:55 AM



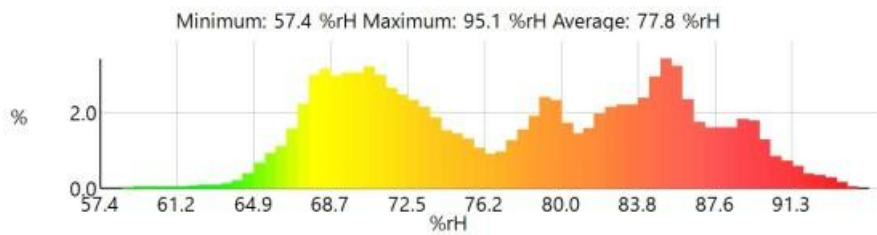
Picture parameters:

Emissivity: 0.93
Refl. temp. [°C]: 20.0

Picture markings:

Measurement Objects	Humidity [%rH]	Emiss.	Refl. temp. [°C]	Remarks
Cold spot 1	95.1	0.93	20.0	-
Hot spot 1	57.4	0.93	20.0	-
Average Area 1	81.4	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

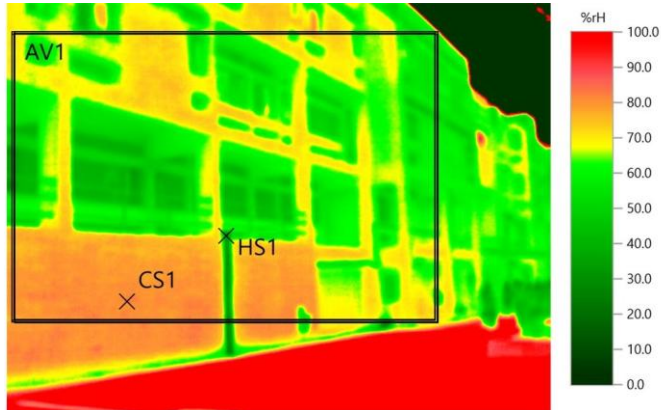
File: IR002445.BMT

Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 12:47:05 AM



Picture parameters:

Emissivity: 0.93
 Refl. temp. [°C]: 20.0

Picture markings:

Measurement Objects	Humidity [%rH]	Emiss.	Refl. temp. [°C]	Remarks
Cold spot 1	84.2	0.93	20.0	critical point
Hot spot 1	27.8	0.93	20.0	-
Average Area 1	63.8	0.87	20.0	-

Histogram:



Energy audit for the faculty of science and technology

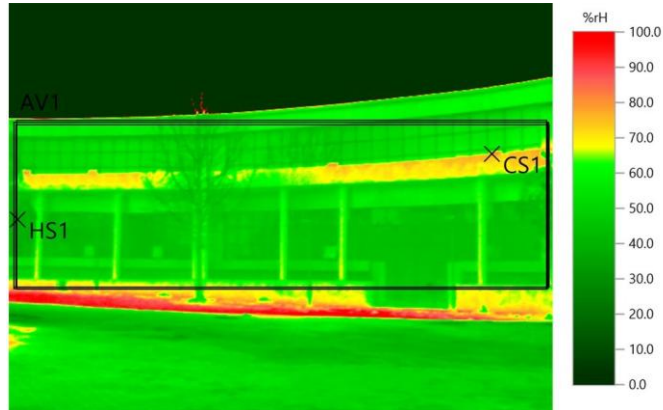
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Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:02:12 AM



Picture parameters:

Emissivity: 0.93
 Refl. temp. [°C]: 20.0

Picture markings:

Measurement Objects	Humidity [%rH]	Emiss.	Refl. temp. [°C]	Remarks
Cold spot 1	80.6	0.93	20.0	-
Hot spot 1	37.4	0.93	20.0	-
Average Area 1	51.6	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

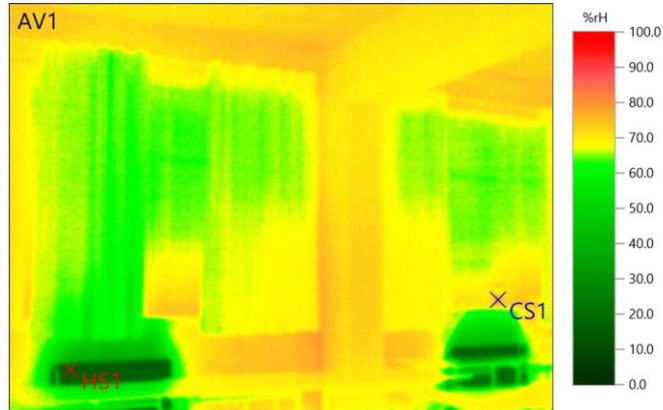
File: IR002456.BMT

Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:08:46 AM



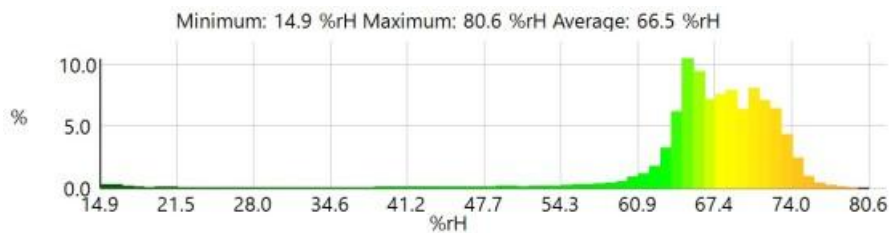
Picture parameters:

Emissivity: 0.93
 Refl. temp. [°C]: 20.0

Picture markings:

Measurement Objects	Humidity [%rH]	Emiss.	Refl. temp. [°C]	Remarks
Cold spot 1	80.6	0.93	20.0	-
Hot spot 1	14.9	0.93	20.0	-
Average Area 1	71.7	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

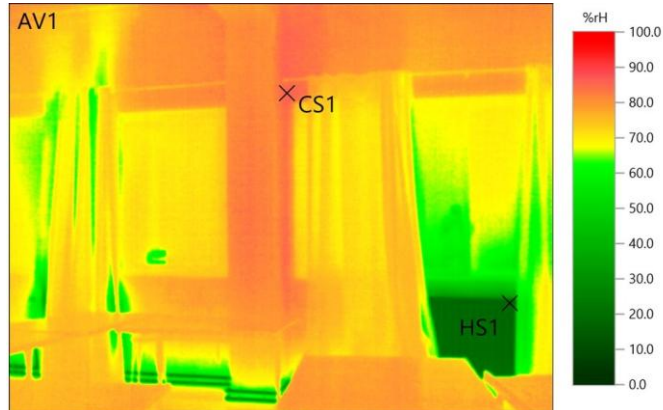
File: IR002460.BMT

Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:15:20 AM



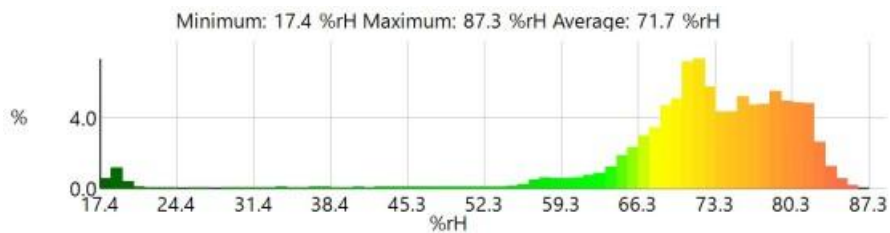
Picture parameters:

Emissivity: 0.93
Refl. temp. [°C]: 20.0

Picture markings:

Measurement Objects	Humidity [%rH]	Emiss.	Refl. temp. [°C]	Remarks
Cold spot 1	87.3	0.93	20.0	-
Hot spot 1	17.4	0.93	20.0	-
Average Area 1	79.8	0.93	20.0	-

Histogram:



Energy audit for the faculty of science and technology

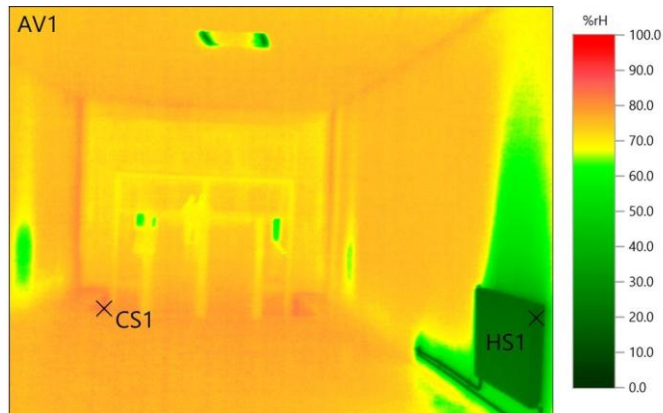
File: IR002467.BMT

Date: 02-02-2025

lens type: 42° x 32°

lens serial no.: 20299670

Time: 1:22:09 AM



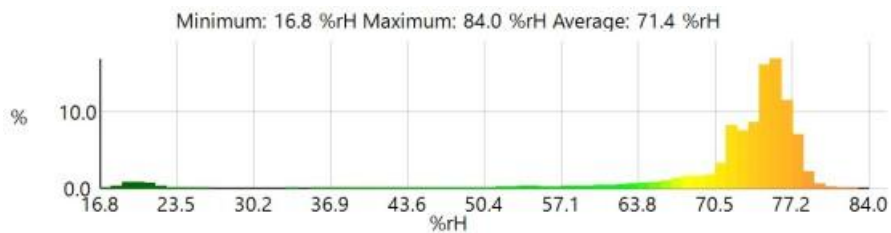
Picture parameters:

Emissivity: 0.93
Refl. temp. [°C]: 20.0

Picture markings:

Measurement Objects	Humidity [%rH]	Emiss.	Refl. temp. [°C]	Remarks
Cold spot 1	84.0	0.93	20.0	-
Hot spot 1	16.8	0.93	20.0	-
Average Area 1	73.8	0.93	20.0	-

Histogram:



Conclusion

This chapter established the implementation procedures for the energy audit, combining tariff analysis, energy classification, and regression-based modeling of heating demand. Electricity and natural gas consumption profiles confirmed strong seasonality, with heating dominating winter demand. Using EU energy class benchmarks and EN 15217/ISO 52000 methodology, the faculty was classified between Class D and E, with significant variation across blocks depending on use.

Regression results indicated that heating accounts for over 90% of demand, with base loads at 9%. Teaching blocks (A–C) dominate absolute consumption, while laboratories and workshops show the highest intensities. This points to two priorities: retrofitting large teaching spaces for volume-driven savings, and targeting labs with insulation, and ventilation measures for intensity-driven reductions.

Overall, the chapter demonstrates a clear, data-driven pathway for prioritizing retrofit measures. It provides the analytical foundation for Chapter 4, where targeted interventions are proposed to reduce both absolute consumption and specific intensities, thereby improving the energy class of the faculty.

Chapter 4: Technical and Economic Analysis

Introduction

In this final chapter, the collected data and proposed measures are synthesized to assess their technical and economic feasibility. By analyzing potential savings, payback periods, and implementation scenarios, the chapter also advances a set of measures and improvements intended to reduce energy consumption. through the application of RetScreen software we can explore the relationship between energy use and economic.

The analysis provides decision-makers with a clear basis for improving energy efficiency across campus facilities, and evaluating the technical and economic viability of potential retrofit scenarios under time and budget limitations. In this way, the chapter contributes both a practical framework and actionable insights to guide decision-making.

This study has examined the energy performance of the Faculty of Technology, with a focus on diagnosing major sources of loss and proposing targeted solutions. The analysis has shown that the faculty suffers from low energy efficiency, with losses primarily linked to user behavior, construction deficiencies, and low-quality equipment.

this chapter presents a summary of the main results, evaluates the relevance of the corrective measures suggested, and provides a critical perspective on the adopted methodology. It also opens the way for future avenues of research and optimization, in line with national and global ambitions regarding energy transition and sustainable development.

4.1 Financial Baseline of the Faculty of Technology

A comprehensive assessment of the university's energy profile requires an examination of both electricity and natural gas expenditures. Billing records for the faculty from 2022 to 2024 were processed and analyzed to account not only for energy consumption levels but also for the tariff structures applied by SONELGAZ. Establishing this financial baseline is essential to evaluating the feasibility of energy conservation measures, as it clarifies the relative weight of electricity and gas costs in the campus budget and highlights where interventions could have the greatest impact.

4.1.1 Electricity

The evaluation of monthly electricity payments for the faculty over the three reference years (2022–2024) shows that the profile is relatively stable across years, electricity expenditures at the faculty represent a significant share of operating costs, despite electricity accounting for a modest proportion of total delivered energy in kWh, its higher unit cost under Tariff code increases its financial weight. the consistency of this pattern across the three years is illustrated in (Figure 28).

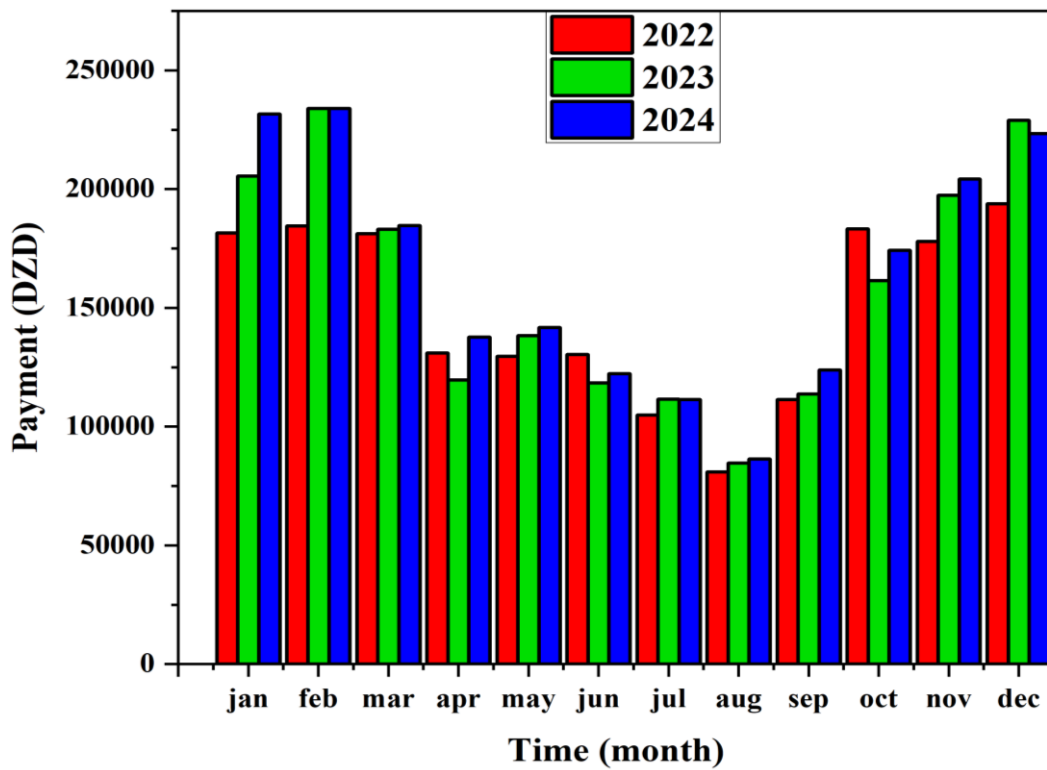


Figure 28. Faculty Monthly electricity payment (2022–2024)

Figure 28 highlights the seasonal variation in electricity bills. Expenditures peak during the colder months (January–March and November–December), typically ranging from 180,000 to 240,000 DZD/month, while summer values (July–August) drop to around 80,000–100,000 DZD/month. This pattern reflects the indirect link between electricity

demand and heating operations, since circulation pumps and auxiliary systems operate more intensively in winter.

4.1.2 Natural gas

As for the evaluation of monthly gas payments for the faculty over the same period, natural gas represents the dominant share of energy cost highlighting that heating is the primary driver of the faculty energy budget. The consistency of the analysis results confirms the financial significance of natural gas, as illustrated in (Figure 29).

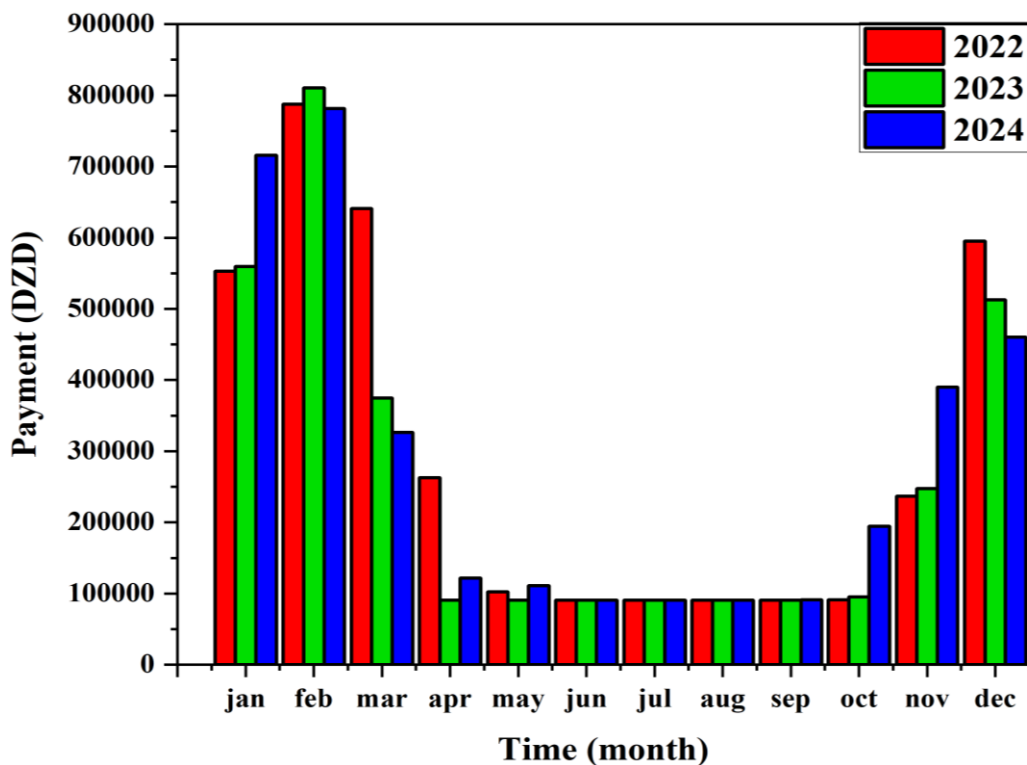


Figure 29. Faculty Monthly gas payment (2022–2024)

As shown in (Figure 29), gas expenditures follow a sharp seasonal cycle, peaking in winter when the central boilers are fully loaded, Winter months (January–March and November–December) account for the majority of costs, with February bills regularly exceeding 750,000–800,000 DZD, while summer payments fall to the contractual minimum of about 90,800 DZD.

This strong seasonality reflects the central role of gas-fired boilers in meeting heating demand and confirms the predominance of space heating in the energy mix.

4.1.3 Payment analysis

The processed billing data confirm that natural gas overwhelmingly dominates the faculty energy consumption profile accounting for 62–67% of total costs, while electricity represents 33–38%.and shows that annual energy expenditures range between 5.0 to 5.4 million DZD, as we can see in (table 16)

Table 16. Annual energy expenditures (2022–2024)

Year	Electricity (DA)	Gas (DA)	Total (DA)	Elec Share (%)	Gas Share (%)
2022	1,790,893	3,632,151	5,423,044	33.00%	67.00%
2023	1,896,788	3,145,609	5,042,397	37.60%	62.40%
2024	1,975,547	3,465,147	5,440,694	36.30%	63.70%

The financial breakdown shows that natural gas accounts for nearly two-thirds of annual energy spending, while electricity accounting for only a small fraction of delivered kWh but represent roughly one-third of costs because of the higher unit price imposed by higher tariff rate.

These findings are consistent with the regression analysis in Chapter 3, which attributed approximately 91% of annual energy consumption to heating loads and only 9% to base demand.

This financial profile provides a clear guide for selecting energy conservation measures (ECMs). Reducing gas consumption directly addresses the primary driver of campus expenditures, while electrical measures target a smaller yet costly share of the budget that is large compared to its kWh contribution, these strategies offer a balanced approach tackling both the seasonal burden of heating and the baseline electricity demand.

4.2 Energy conservation measures (ECMs)

After establishing the energy and financial baselines, our next task was to identify a suitable set of ECMs that fit our faculty, to address the main sources of energy loss and align with our regression analysis, to target both natural gas and electricity consumption.

To propose an effective set of ECMs, it was first necessary to understand where and how energy losses occur within the faculty buildings. Identifying these losses made it possible to prioritize the interventions that would have the greatest impact on both energy use and financial performance.

To achieve this, we used a combination of methods, including site observations, thermal imaging, occupants' questionnaires, and the analysis of energy consumption data. The results from these diagnostic activities provided valuable insights into the main sources of inefficiency across the campus. The investigation revealed that energy losses occur primarily from the following domains:

- **Building Envelope Inefficiency:** Many campus buildings particularly the older blocks, were found to have old single-glazed windows, insufficient insulation, and unsealed openings around doors and window frames. thermography images confirmed significant heat transfer through glazing and air leakage zones.
- **Lighting System Inefficiency:** A large proportion of classrooms and administrative areas still rely on fluorescent or incandescent lamps, which consume excessive electricity and produce unnecessary heat, and we also notice that lights are often left operating during daylight hours or in unoccupied rooms due to the absence of automatic control systems.
- **Heating System and Boiler Inefficiency:** The audit of the central heating plant revealed that the existing boilers operate below their nominal efficiency, primarily due to insufficient maintenance, poor combustion tuning, and the absence of modern control systems.
- **Air Infiltration and Poor Control:** Many buildings showed significant air infiltration, particularly through door gaps, poorly fitted windows, and unsealed joints. This uncontrolled exchange between indoor and outdoor air increases heat losses and leads to higher heating demand during the winter season.

- **User behavior and Control Issues:** The audit revealed that lights and HVAC systems are often left on when rooms are empty, installing timers and occupancy sensors would help prevent unnecessary energy use.

Based on the site measurements and analysis, the distribution of energy losses was concluded in (table number) as follows:

Table 17. Energy losses distribution

Category	Total energy use contribution	Key issues
Heating	30%	outdated boiler systems, lack of controls
Lighting	20%	inefficient lamps, continuous operation, no sensors
Building envelope	40%	envelope heat loss, single glazing, poor insulation, infiltration
Equipment and others	10%	user behavior, plug loads, old appliances

When evaluating the financial feasibility of ECMs, we faced a major challenge related to the subsidized energy tariffs applied at the campus. Electricity tariff price is 5 DZD/kWh, while natural gas is priced at only 0.6 DZD/kWh. Because of these low prices, the savings from ECMs are large in terms of energy (kWh) but small in financial value. To deal with this, we focused on finding measures that could reduce energy use and still provide reasonable cost savings with low investment requirements under the current tariff structure.

After This analysis that highlights the most significant energy losses and the challenge related to the subsidized energy tariffs prices, the ECMs were carefully selected to address these issues and achieve both energy and financial savings.

4.2.1 Double Glazing of Windows

Double glazing involves using two panes of glass separated by a sealed space filled with air or an insulating gas like argon to create an insulated glass unit. This structure significantly reduces heat transfer, improving thermal insulation, and also provides

excellent acoustic insulation by dampening sound waves. Double glazing enhances energy efficiency, comfort and security while reducing energy bills and condensation. Our goal in using secondary glazing is to reduce energy losses by lowering the thermal transmittance (U-value) of the windows from approximately $5.7 \text{ W/m}^2\cdot\text{K}$ (single glazing) to around $3.0\text{--}3.3 \text{ W/m}^2\cdot\text{K}$ (double glazing). This can be achieved by replacing the existing single panes with sealed double-glazed insulating glass units (4/6/4, air-filled, aluminum spacer) installed within the existing frames. This glazing-only retrofit approach allowed us to significantly reduce costs compared to a full window replacement (figure 30).[29]

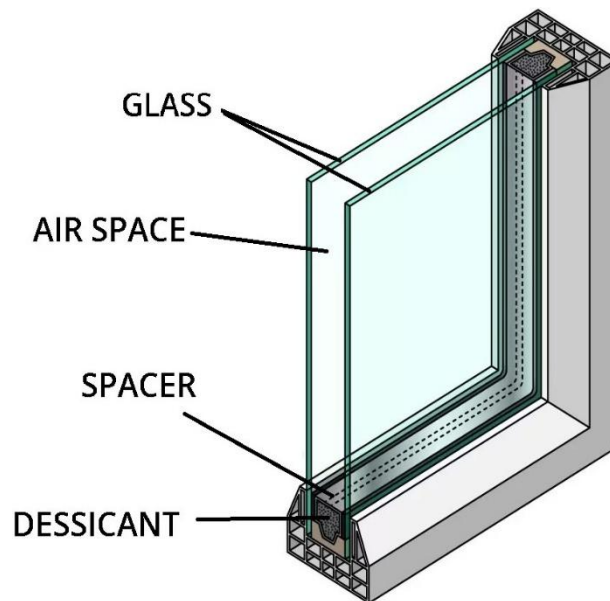


Figure 30. Insulated glass unit

The specifications of the chosen type of insulating glass units are as follows:

- **Technical description:** a Standard double glazing, 4/6/4, set consisting of 4 mm colorless Float exterior glazing, dehydrated air gap with an aluminum separating profile and a double perimeter seal, 6 mm, and 4 mm thick colorless Float interior glazing, for panes with a surface area of less than 2 m^2 ; 14 mm total thickness, fixing on joinery with wedging using perimeter and lateral support

wedges, cold sealing with colorless synthetic silicone, compatible with the support material, for panes with a surface area of less than 2 m².

- **Price justification:** the installed unit price is (3,748.59 DA/ m²) according to the Algerian construction guide and the size of each window is 1.2 m².
- **Target:** 8.5% heating load reduction.

We calculated the costs for the double glazing, and the total investment for this measure is (5,776,459 DZD) split across campus building as illustrated in (table 18).

Table 18. Glazing total investment per block

Block	Area (m ²)	Window Count	Window Area (m ²)	glazing investment (DA)
Block A	5,563.20	311	373.2	1399126.8
Block B	3,347.24	173	207.6	778292.4
Block C	1,022.80	68	81.6	305918.4
PAUWES	809.1	46	55.2	206944.8
Registrar's Office	543.8	28	33.6	125966.4
Administration	1,022.36	49	58.8	220441.2
Research Laboratory	2,157.20	94	112.8	422887.2
Distance Learning	1,770.60	74	88.8	332911.2
Automation Lab	1,717.34	77	92.4	346407.6
Laboratory (general)	1,470.20	73	87.6	328412.4
Lecture Halls	860.3	36	43.2	161956.8
Library	885.2	51	61.2	229438.8
Mechanical Dept.	690.53	47	56.4	211443.6
Architecture (new)	1,726.33	83	99.6	373400.4
Technology Hall	764.24	35	42	157458
Security Office	322.87	16	19.2	71980.8
Conference Hall	433.34	23	27.6	103472.4
Total	25,106.55	1284	1540.8	5776459.2

4.2.2 Centralized Boiler Control System

A centralized boiler control system acts as the brain of the heating plant, linking all boilers, pumps, valves, and sensors to a single master controller. This controller

continuously collects data such as water temperature, outdoor temperature, pressure, and system demand. Based on this information, it automatically determines how many boilers should operate, at what firing rate, and when they should switch on or off to maintain efficient performance.

A centralized boiler control system saves energy mainly through efficiency optimization and smart staging. Unlike conventional setups where boilers operate independently and respond only to local thermostats or manual switches, the centralized system coordinates all components to maintain optimal performance. It prevents poor load sharing, reduces energy consumption, and minimizes maintenance problems by running only the number of boilers required to meet current demand at their most efficient firing rate. Additionally, it keeps operation within safe limits and allows for remote monitoring and fault detection.

The specifications of the chosen type of Centralized Boiler Control System are as follows:

- **Technical description:** Centralized control of the heating and DHW system, for four boilers, eight radiator circuits and DHW production, consisting of an electronic control unit for heating and DHW, three control units and eight room modules for the radiator circuit and centralized control Interface. Fully assembled, connected and tested. [29]
- **Target:** 15 % heating load reduction.

The total investment for the Centralized Boiler Control System is (744,326 DZD) split across campus building as illustrated in (table 19).

Table 19. Control total investment per block

Block	Control investment (DA)
Block A	138682.46
Block B	83441.81
Block C	25496.91
PAUWES	19209.22
Registrar's Office	12910.61
Administration	24272.33
Research Laboratory	102430.19
Distance Learning	46240.31
Automation Lab	89698.78
Laboratory (general)	55847.53
Lecture Halls	18382.31
Library	19965.15
Mechanical Dept.	19673.04
Architecture (new)	45084.17
Technology Hall	27216.27
Security Office	6515.6
Conference Hall	9259.32
Total	744,326

4.2.3 LED lighting replacement

Lighting replacement involves removing existing inefficient lighting usually fluorescent or incandescent and replacing them with efficient LED lighting, LED replacement reduces not only energy bills but also maintenance costs and energy efficiency.

Lighting accounts for a significant portion of electricity consumption in campus buildings, replacing outdated lighting with LEDs is one of the most effective and fastest payback energy saving upgrades available.

The specifications of the chosen type of LED lighting are as follows:

- **Technical description:** Plastic LED tube T8/120/G13, it emits bright white light with a color temperature of 6500 K and a color rendering index of 80. Operating with a voltage rating of 280 V and a power factor of 0.5, with a 3-year warranty.

- **Price justification:** the installed unit price is (300 DA/unit) according to the Algerian local market. The LED density is 1 LED tube per 10 m².
- **Target:** 15% Base load reduction.

The total investment for LED lighting replacement is (753,199 DZD) split across campus building as illustrated in (table 20).

Table 20. LED total investment per block

Block	LED Count	LED investment (DA)
Block A	556	166896
Block B	335	100417
Block C	102	30684
PAUWES	81	24273
Registrar's Office	54	16314
Administration	102	30671
Research Laboratory	216	64716
Distance Learning	177	53118
Automation Lab	172	51520
Laboratory (general)	147	44106
Lecture Halls	86	25809
Library	89	26556
Mechanical Dept.	69	20716
Architecture (new)	173	51790
Technology Hall	76	22927
Security Office	32	9686
Conference Hall	43	13000
Total	2510	753199

4.2.4 Boiler Tune-Up and Combustion Optimization

Boiler tune-up involves inspecting, cleaning, and adjusting the combustion system of the existing gas fired boilers to restore optimal efficiency. Over time, soot deposits, incorrect burner settings, and excess air lead to incomplete combustion and unnecessary

fuel losses, proper maintenance and calibration reduce these losses and ensure the boilers operate near their rated performance.

This measure directly targets the heating energy, which represents the largest portion of the campus load. It improves fuel utilization efficiency and reduces flue gas heat losses, providing immediate savings with very low investment compared to major retrofits.

The specifications for the Boiler Tune-Up and Combustion Optimization are as follows:

- **Technical description:** Full boiler combustion analysis and re-tuning, including adjusting the air-fuel ratio to reduce excess air and flue gas losses, fixing leaks and pump controls, cleaning burners and heat transfer surfaces, and performed by a qualified technician following standard procedures.
- **Price justification:** we set a budget for each block based on the heating needs, area and the number of radiators, and based on the local market for boiler maintenance contracts.
- **Target:** 2-3% heating load reduction.

The total investment for Boiler Tuning is (2,600,000 DZD) split across campus building as illustrated in (table 21).

Table 21. Boiler tuning investment per block

Block	boiler tuning investment (DA)
Block A	200000
Block B	200000
Block C	150000
PAUWES	150000
Registrar's Office	50000
Administration	150000
Research Laboratory	200000
Distance Learning	200000
Automation Lab	200000
Laboratory (general)	200000
Lecture Halls	150000
Library	150000
Mechanical Dept.	150000
Architecture (new)	200000
Technology Hall	150000
Security Office	50000
Conference Hall	50000
Total	2,600,000

4.2.5 Infiltration Sealing

Infiltration sealing aims to reduce unwanted air leakage through cracks, joints, and unsealed openings in doors, windows, and wall interfaces. Excess infiltration increases the heating load by allowing conditioned air to escape and cold outside air to enter the building. Improving the air-tightness of the envelope reduces heat loss, stabilizes indoor temperatures, and improves occupant comfort, particularly in winter.

This measure directly targets the heating energy, which dominates the campus's consumption pattern. It is inexpensive and easy to implement, making it one of the most cost-effective efficiency actions.

The specifications for the Infiltration sealing are as follows:

- **Technical description:** Application of weather stripping on external doors, installation of door sweeps, sealing of window frames with silicone caulking, and

filling of wall penetration gaps, the work will be verified using simple smoke or pressure-test checks to identify remaining leakage zones.

- **Price justification:** we set a budget for each block based on the observation we did and the area of each block, using local market suppliers' prices.
- **Target:** 5 % heating load reduction.

The total investment for Infiltration sealing is (1,550,000 DZD) split across campus building as illustrated in (table 22).

Table 22. Infiltration sealing investment per block

Block	Infiltration sealing investment (DA)
Block A	120000
Block B	120000
Block C	80000
PAUWES	80000
Registrar's Office	50000
Administration	80000
Research Laboratory	120000
Distance Learning	120000
Automation Lab	120000
Laboratory (general)	120000
Lecture Halls	80000
Library	80000
Mechanical Dept.	80000
Architecture (new)	120000
Technology Hall	80000
Security Office	50000
Conference Hall	50000
Total	1,550,000

4.2.6 Lighting Timers and Occupancy Sensors

Lighting control measures aim to eliminate unnecessary energy use by ensuring that lights operate only when and where they are needed. At the Faculty of Technology campus, many classrooms, laboratories, and corridors remain illuminated during unoccupied periods, particularly after hours. Installing timers and occupancy sensors allows lights to switch off automatically when spaces are vacant or during daylight hours, thereby reducing both energy waste and maintenance requirements.

This measure directly impacts the campus's base electrical load and works hand in hand with the LED replacement project. Together, they are expected to reduce the base-load electricity consumption by around 20%.

The specifications of the chosen type of Lighting Timers and Occupancy Sensors are as follows:

- **Technical description:** Installation of passive infrared (PIR) or ultrasonic occupancy sensors in classrooms, offices, and laboratories, and programmable timers in corridors, restrooms, and exterior lighting. Sensors will automatically turn off lights after 10–15 minutes of detected inactivity.
- **Price justification:** Based on Algerian local market, the installed cost averages between (800- 1,200 DZD) per sensor and (1,000- 1,500 DZD) per timer, including wiring and configuration. And we use approximately 260 control points across the campus.
- **Target:** 5 % base load reduction.

The total investment for the timers and sensors is (260,000 DZD) split across campus building as illustrated in (table 23).

Table 23. Timers and sensors investment per block

Block	Timers and sensors investment (DA)
Block A	20000
Block B	20000
Block C	15000
PAUWES	15000
Registrar's Office	5000
Administration	15000
Research Laboratory	20000
Distance Learning	20000
Automation Lab	20000
Laboratory (general)	20000
Lecture Halls	15000
Library	15000
Mechanical Dept.	15000
Architecture (new)	20000
Technology Hall	15000
Security Office	5000
Conference Hall	5000
Total	260,000

4.3 Retscreen analysis

To evaluate the overall performance of the proposed energy conservation measures, a comprehensive simulation was carried out using the RETScreen Expert software. The model integrates the campus's baseline energy data, climatic conditions for Tlemcen, and the technical and financial parameters of each ECM. Both the base case and the proposed case were analyzed to estimate annual energy savings, cost reductions, and financial indicators such as payback period, net present value (NPV), and internal rate of return (IRR). The following section presents the RETScreen results for the whole campus, summarizing the technical and economic impact of the combined ECM package.

We calculated the results using two types of investment scenarios, which is normal investment with the full ECMs package, and low investment ECMs package without (double glazing and the boiler control system).

And two types of tariff scenarios, current tariff (electricity 5 DZD/kWh), (gas 0.6 DZD/kWh) and future tariff (electricity 8 DZD/kWh), (gas 2 DZD/kWh).

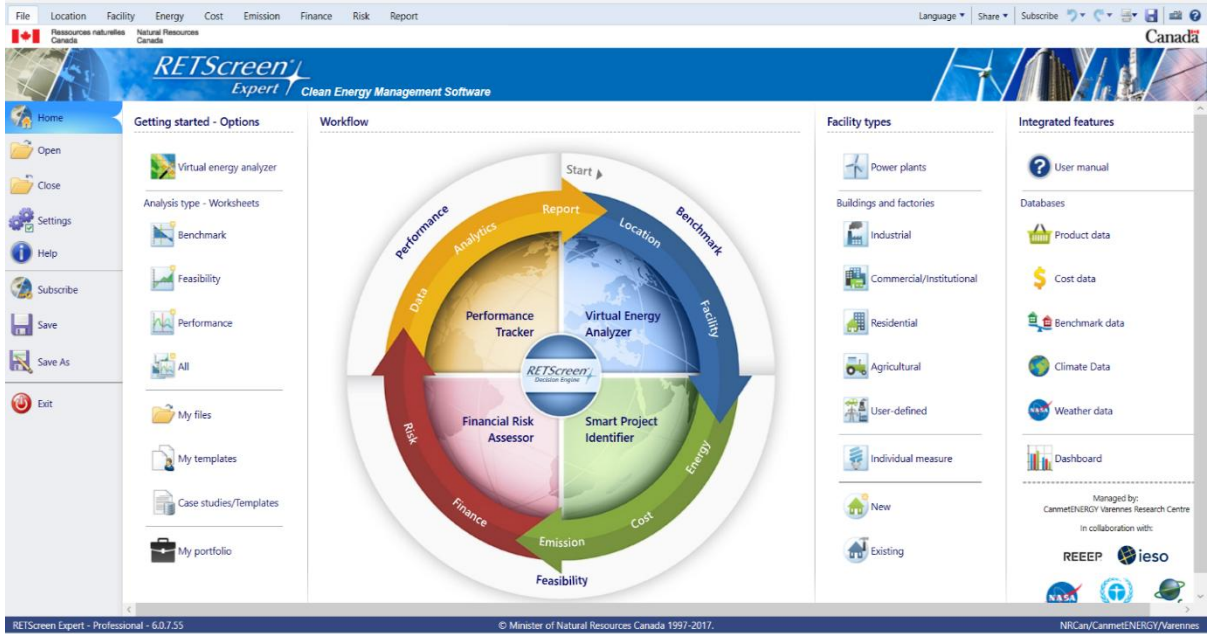


Figure 31. Retscreen interface

Step 1 - Site reference conditions

Unit	Climate data location	Facility location	Source
Latitude	35.0	34.9	User-defined
Longitude	-1.5	-1.3	
Climate zone	3A - Warm - Humid		
Elevation	247	0	
Heating design temperature	3.2		Ground - Ground
Cooling design temperature	34.1		Ground - Ground
Earth temperature amplitude	13.3		NASA

Month	Air temperature °C	Relative humidity %	Precipitation mm	Daily solar radiation - horizontal kWh/m ² /d	Atmospheric pressure kPa	Wind speed m/s	Earth temperature °C	Heating degree-days 18 °C °C-d	Cooling degree-days 10 °C °C-d
January	10.2	73.5%	42.43	2.98	98.0	1.9	12.6	242	6
February	11.2	73.9%	41.43	3.92	97.9	2.0	13.7	190	34
March	13.4	72.0%	34.42	5.14	97.7	2.0	15.8	143	105
April	15.3	66.8%	34.54	6.56	97.4	2.4	18.0	81	159
May	18.4	65.7%	26.97	7.15	97.4	2.4	21.3	0	260
June	22.4	61.6%	7.51	7.65	97.5	2.5	25.5	0	372
July	25.6	58.2%	2.78	7.57	97.5	2.4	28.2	0	484
August	26.1	59.2%	6.23	6.89	97.5	2.3	28.3	0	499
September	23.1	64.9%	23.59	5.75	97.5	2.1	25.5	0	393
October	19.2	69.6%	60.87	4.29	97.6	1.9	21.7	0	285
November	14.8	71.7%	62.10	3.14	97.7	2.1	17.0	96	144
December	11.6	73.9%	51.08	2.65	97.9	2.1	13.8	198	50
Annual	17.6	67.5%	393.94	5.31	97.6	2.2	20.1	950	2,791
Source	Ground	Ground	NASA	NASA	NASA	Ground	NASA	Ground	Ground
Measured at						m	10		0

Figure 32. Tlemcen climate data

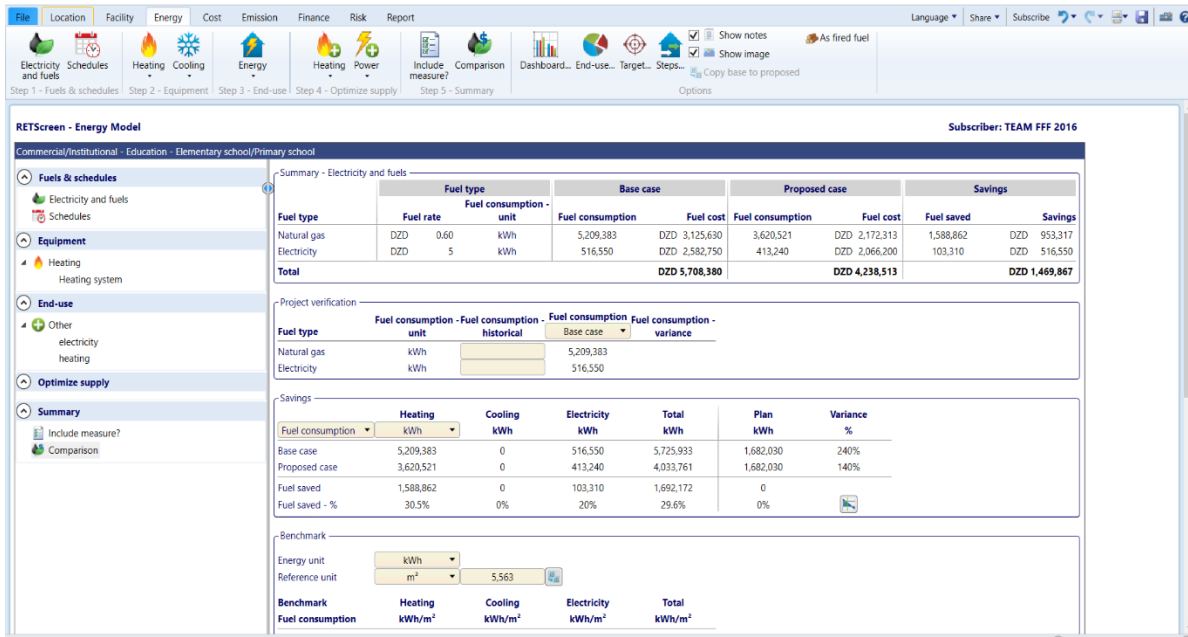


Figure 33. Energy model

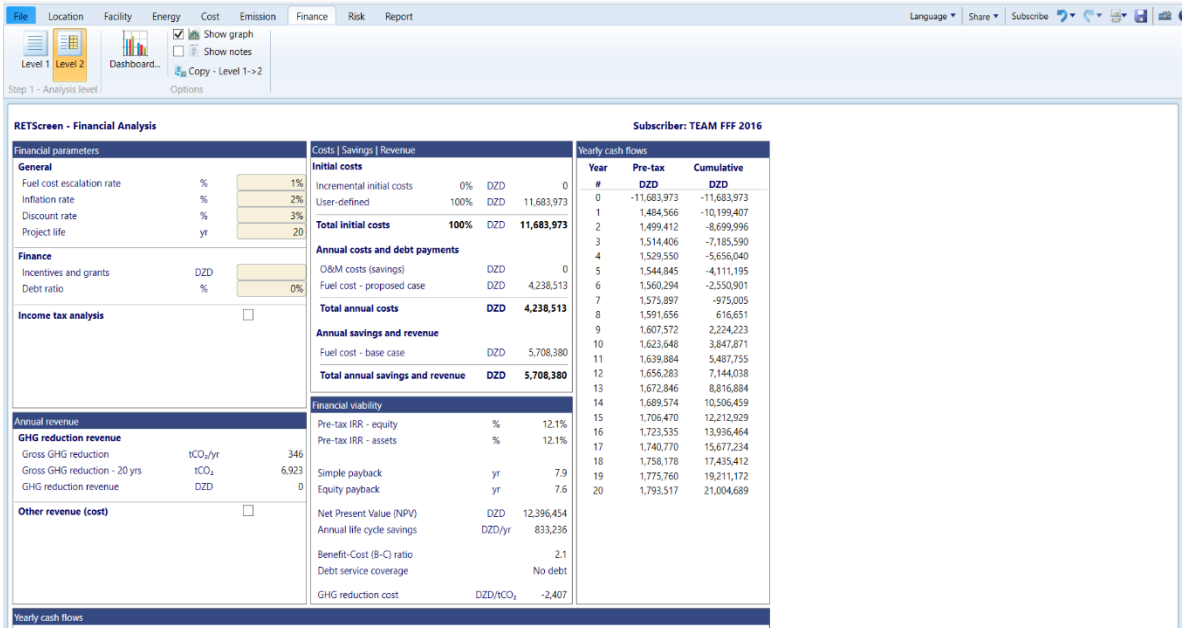


Figure 34. Financial analysis

4.4 Retscreen results per block

- Block A

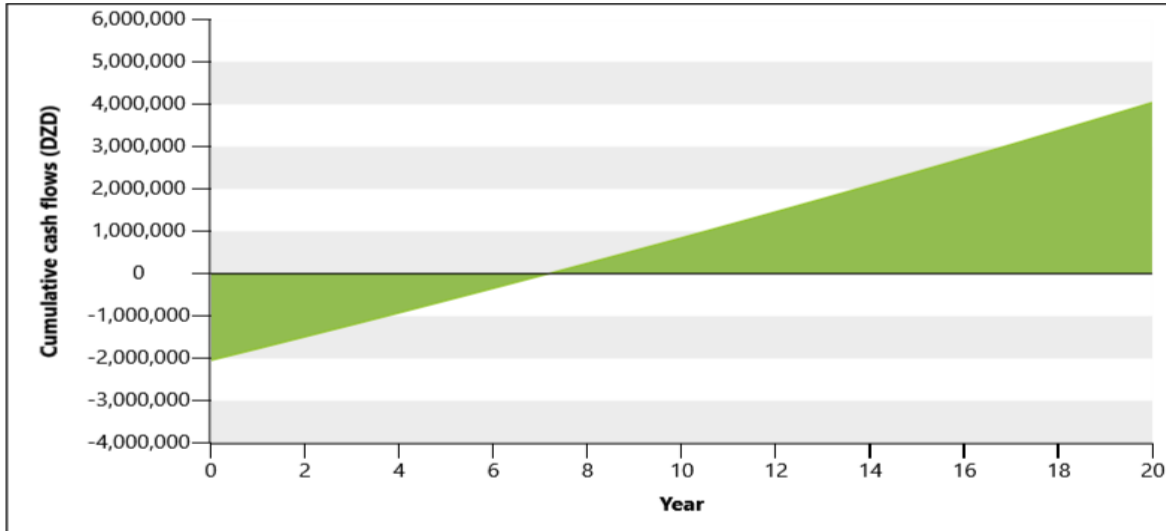


Figure 35. project financial performance at full investment (Block A)

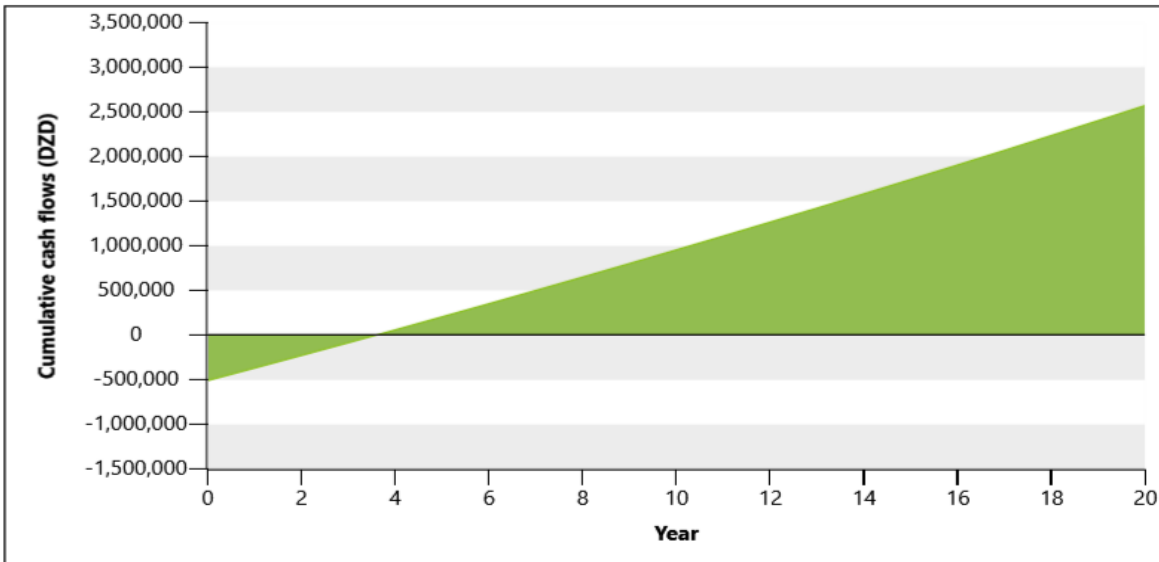


Figure 36. project financial performance at low investment (Block A)

Table 24. Block A results

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	2,044,705	2%	20	7.5	4,045,992	13.1%
Low	506,896	2%	20	3.7	2,573,917	28.4%

• **Block B**

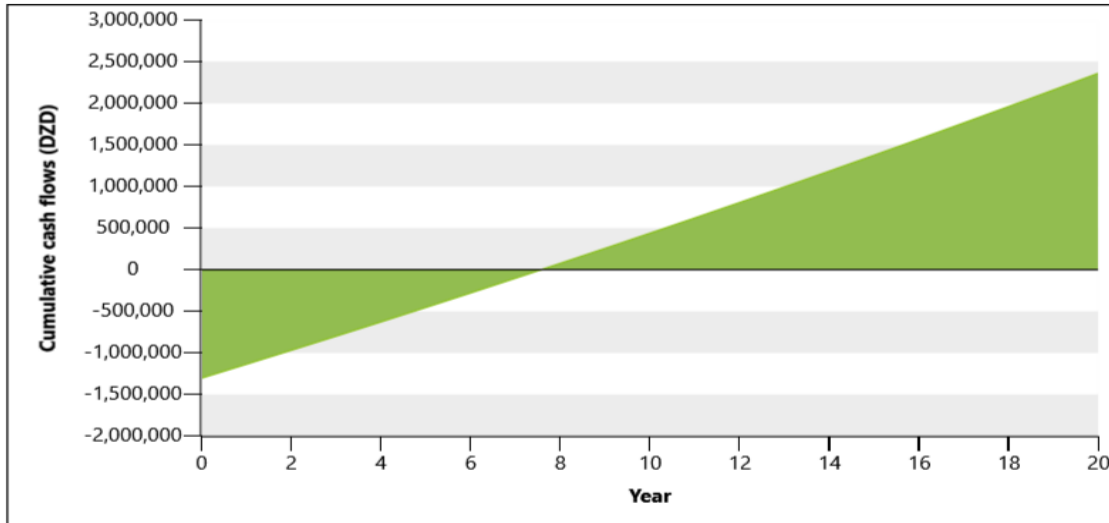


Figure 37. Project financial performance at full investment(Block B)

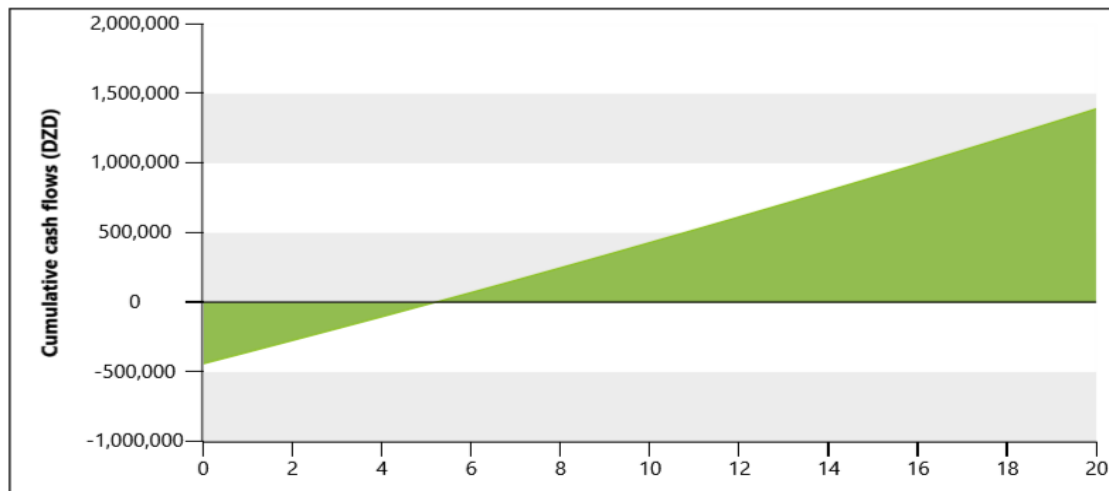


Figure 38. Project financial performance at low investment(Block B)

Table 25. Block B results

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	1,302,152	2%	20	7.9	2,362,329	12.2%
Low	440,418	2%	20	5.3	1,392,812	19.2%

- **Block C**

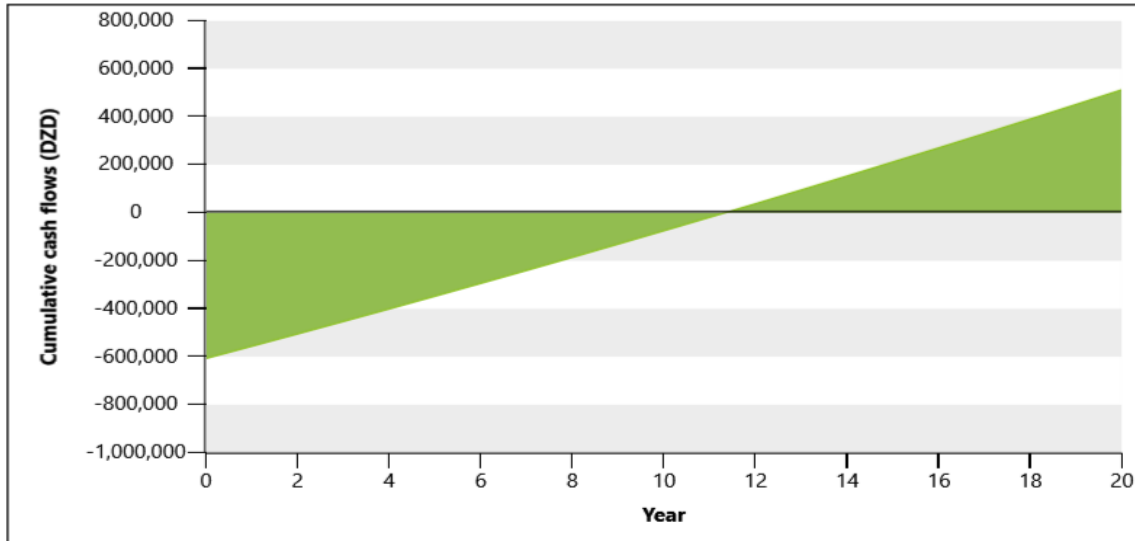


Figure 39. Project financial performance at full investment (Block C)

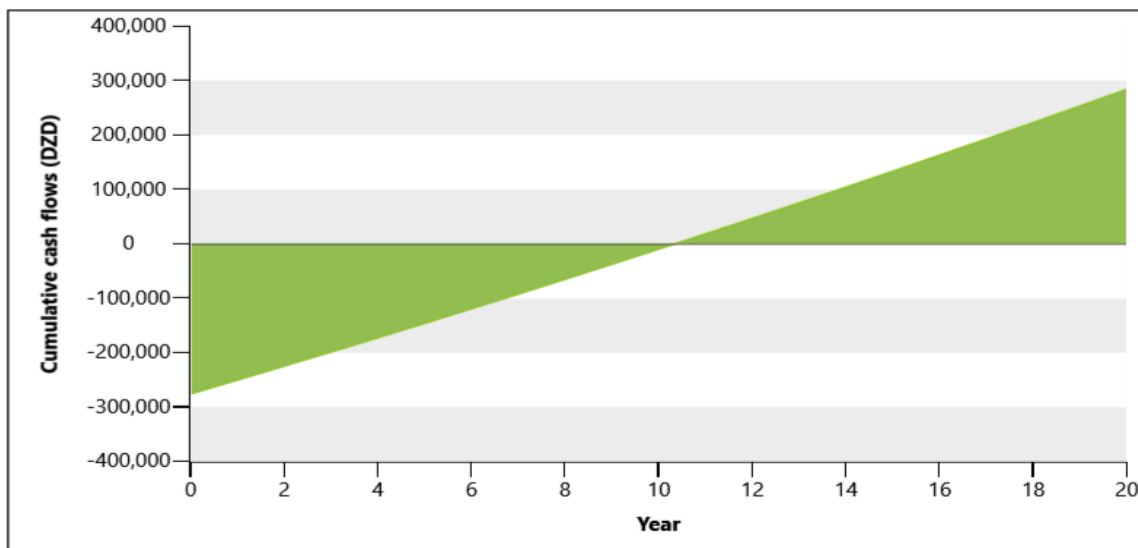


Figure 40. Project financial performance at low investment (Block C)

Table 26. Block C results

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	607,100	2%	20	12.1	512,670	6.5%
Low	275,684	2%	20	10.9	284,511	7.7%

• PAUWES

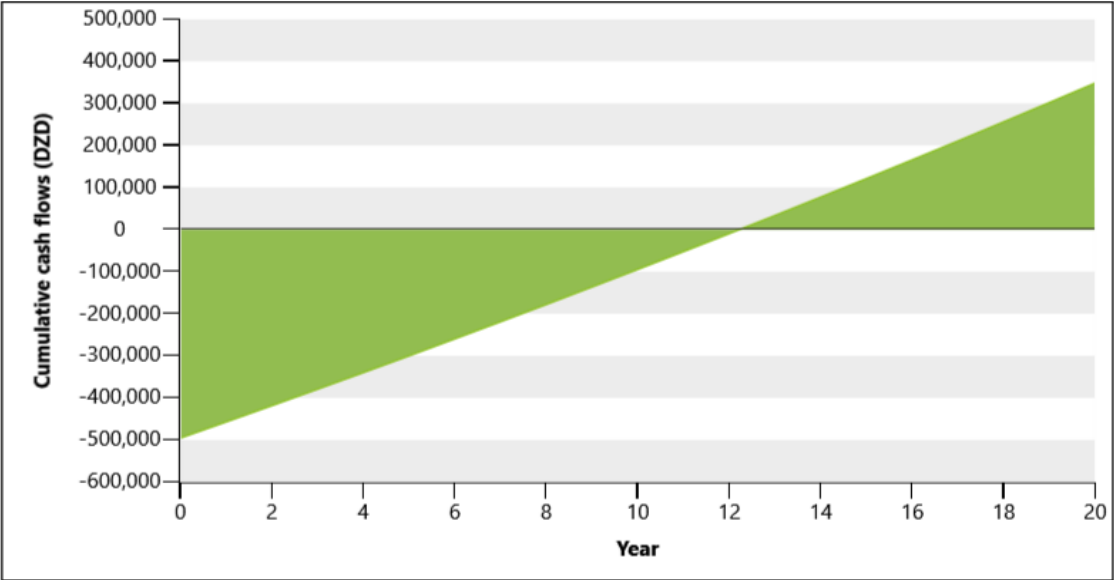


Figure 42. Project financial performance at full investment (PAUWES)

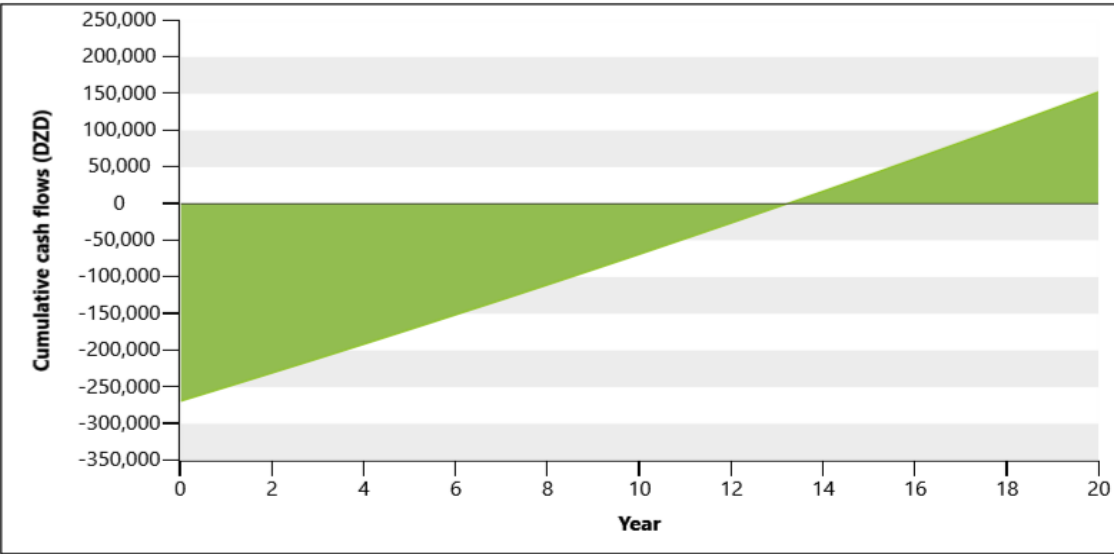


Figure 41. Project financial performance at low investment (PAUWES)

Table 27. PAUWES results

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	495,427	2%	20	13.1	348,172	5.5%
Low	269,273	2%	20	14.2	152,738	4.6%

- Registrar office

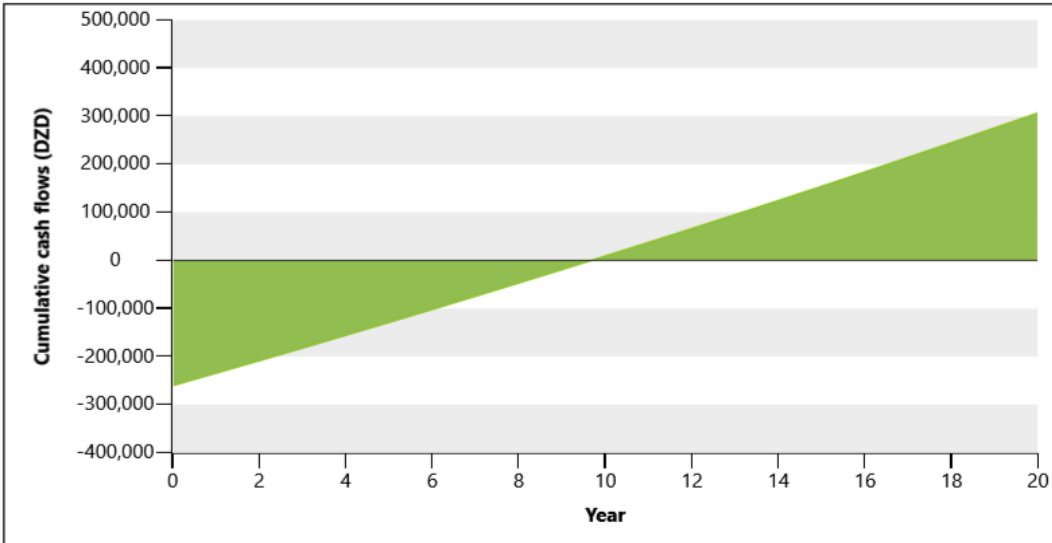


Figure 43. Project financial performance at full investment (Registrar office)

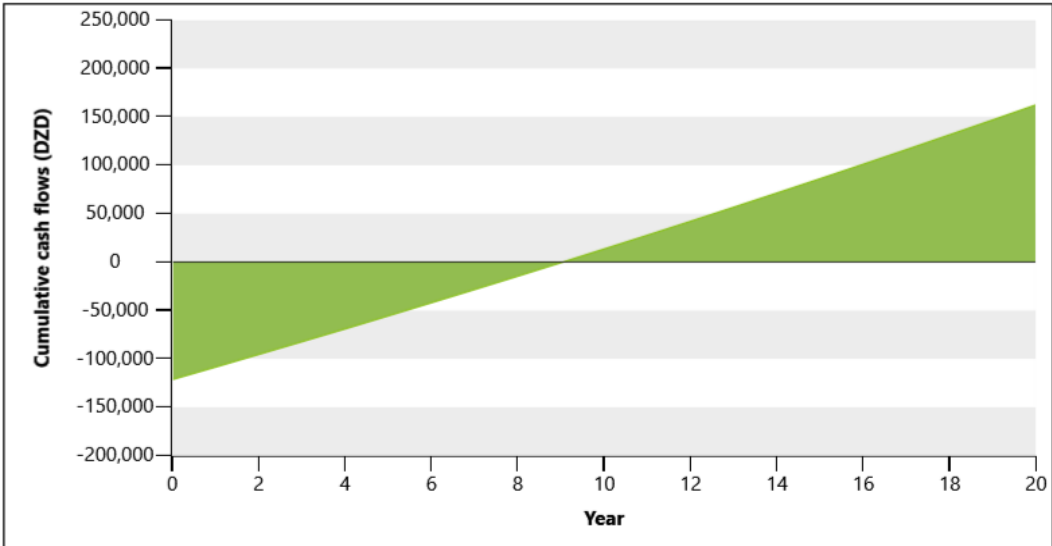


Figure 44. Project financial performance at low investment (Registrar office)

Table 28. Register office results

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	260,191	2%	20	10.2	306,806	8.6%
Low	121,314	2%	20	9.5	162,471	9.5%

• **Administration**

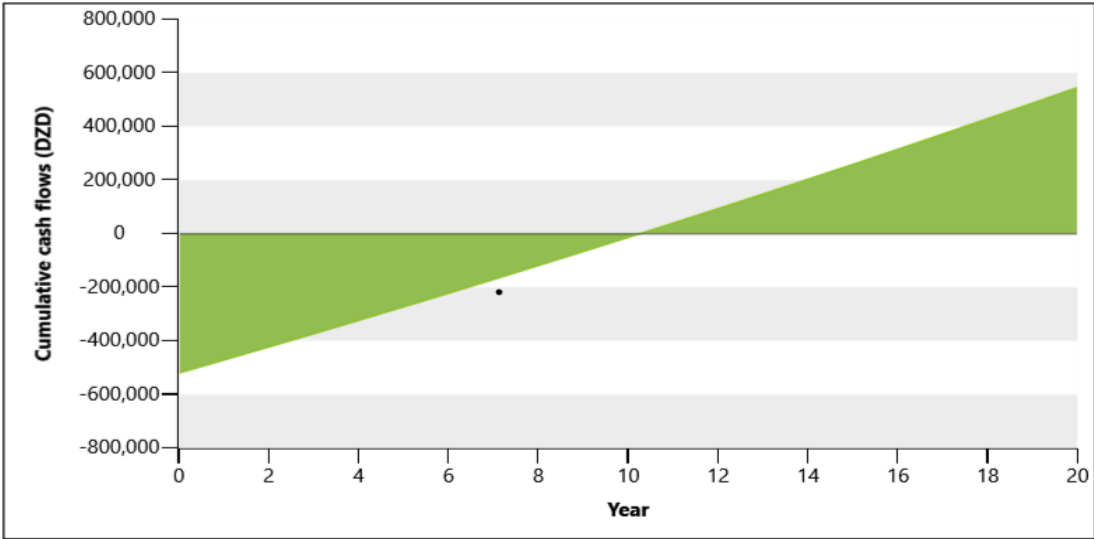


Figure 45. Project financial performance at full investment (Administration)

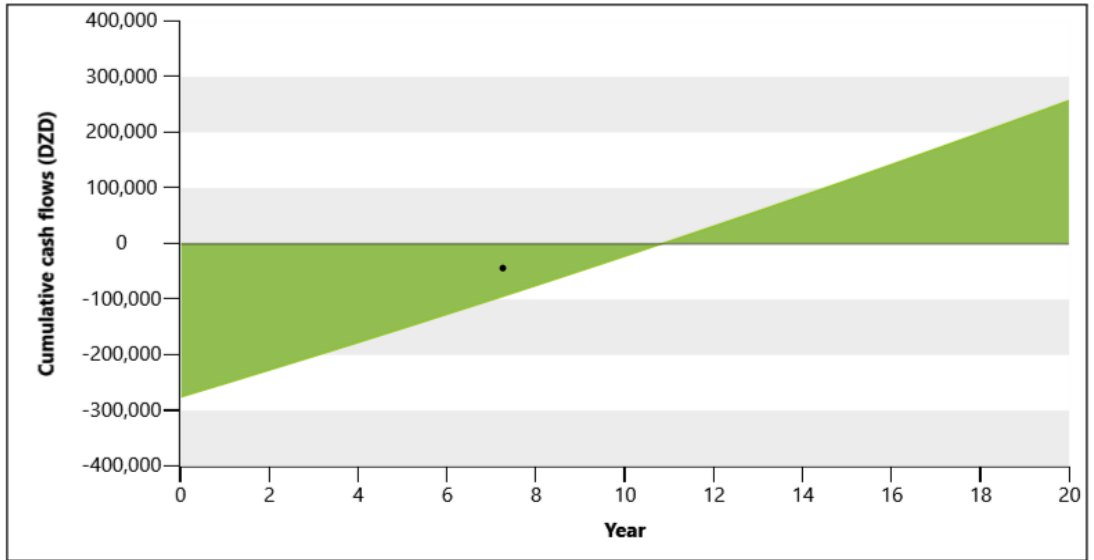


Figure 46. Project financial performance at low investment (Administration)

Table 29. Administration results

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	520,384	2%	20	10.9	545,589	7.8%
Low	275,670	2%	20	11.5	257,616	7.0%

- **Research Laboratory**

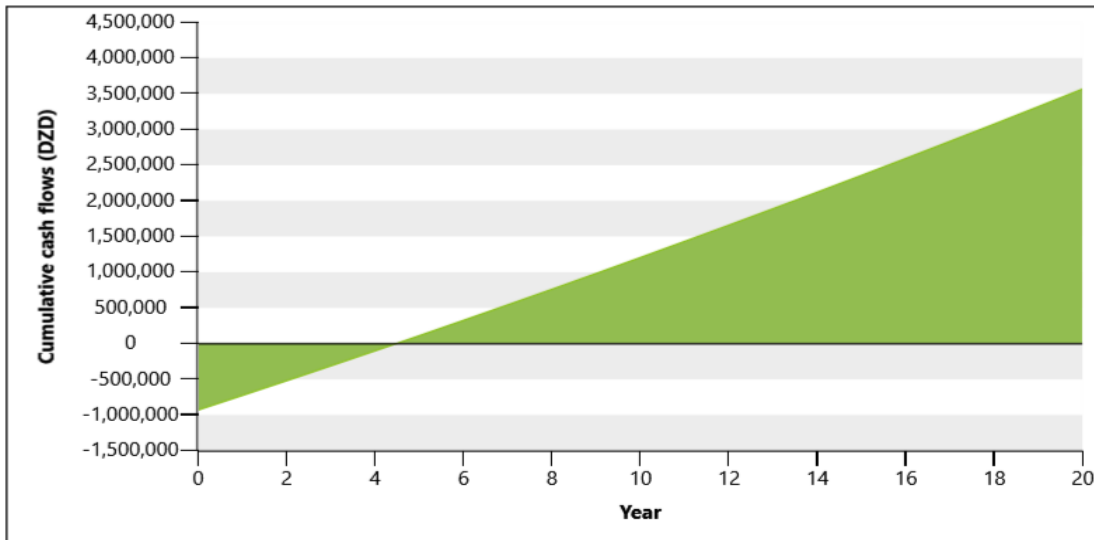


Figure 48. Project financial performance at full investment (Research Laboratory)

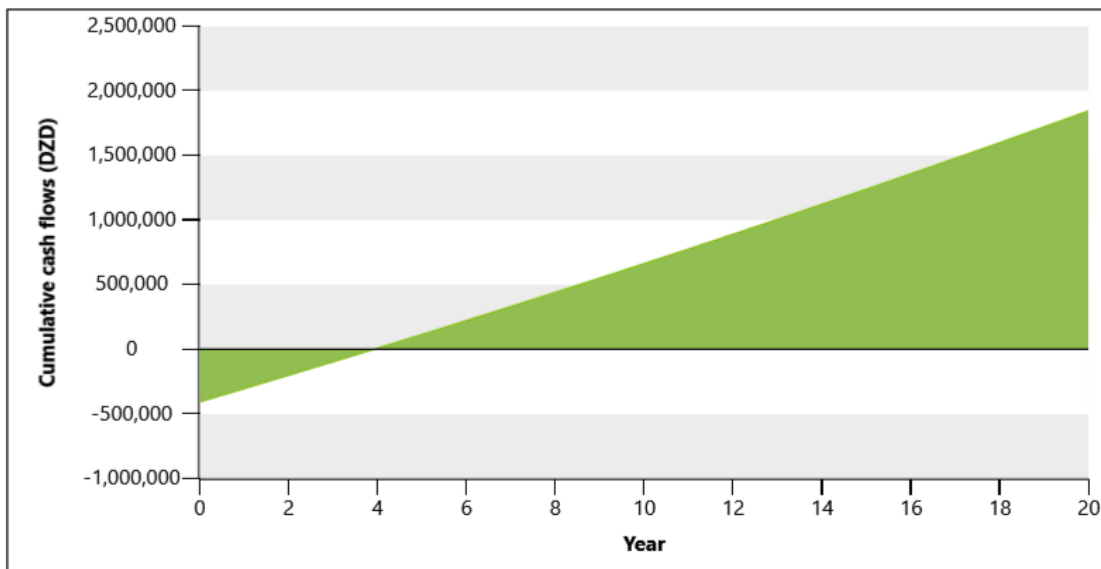


Figure 47. Project financial performance at low investment (Research Laboratory)

Table 30. Research laboratory results

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	930,034	2%	20	4.6	3,568,412	22.5%
Low	404,716	2%	20	4	1,845,761	26.0%

- **Distance learning**

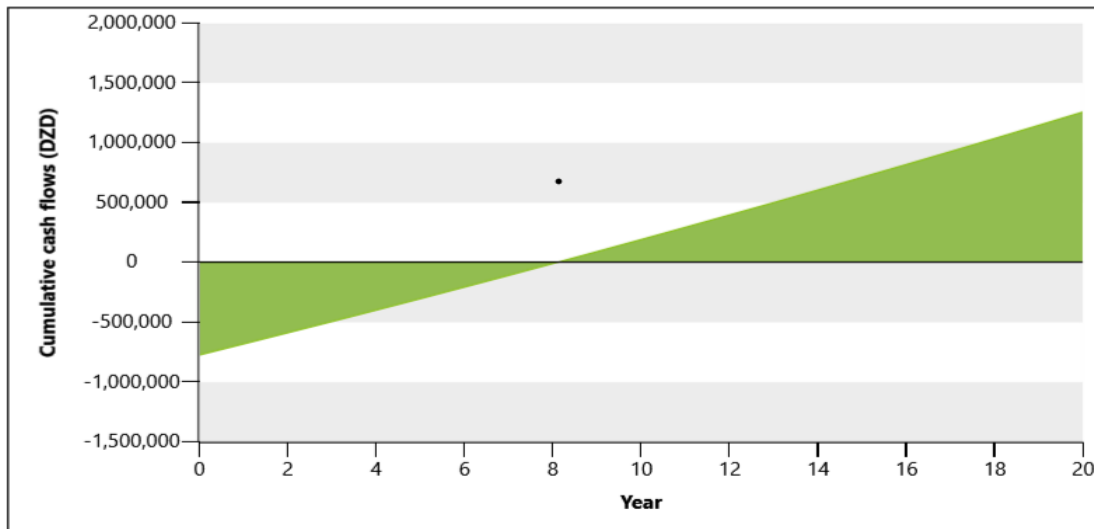


Figure 50. Project financial performance at full investment (Distance learning)

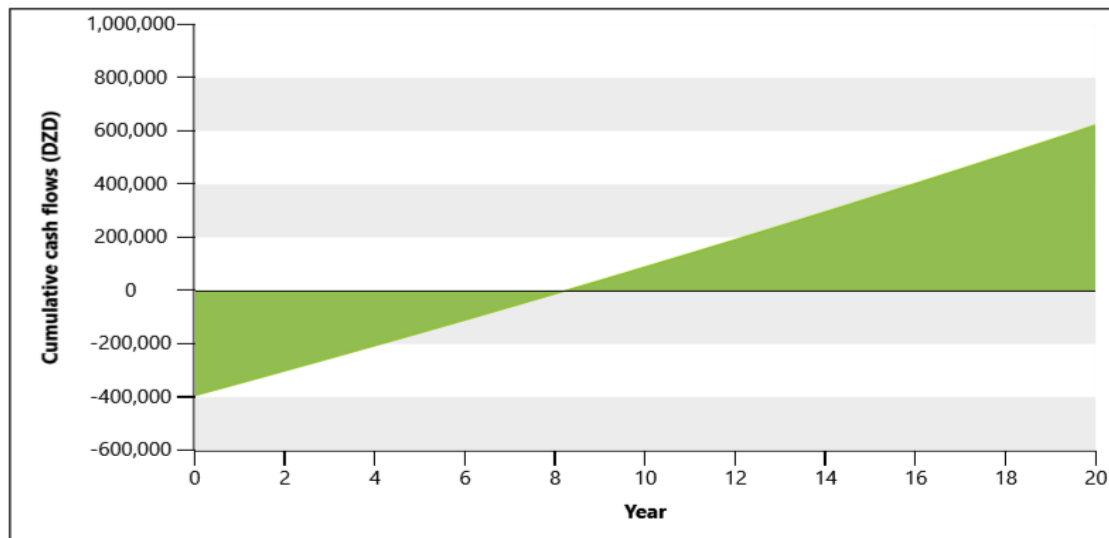


Figure 49. Project financial performance at low investment (Distance learning)

Table 31. Distance learning result

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	772,269	2%	20	8.5	1,258,471	11.2%
Low	393,118	2%	20	8.6	622,821	10.9%

● **Automation lab**

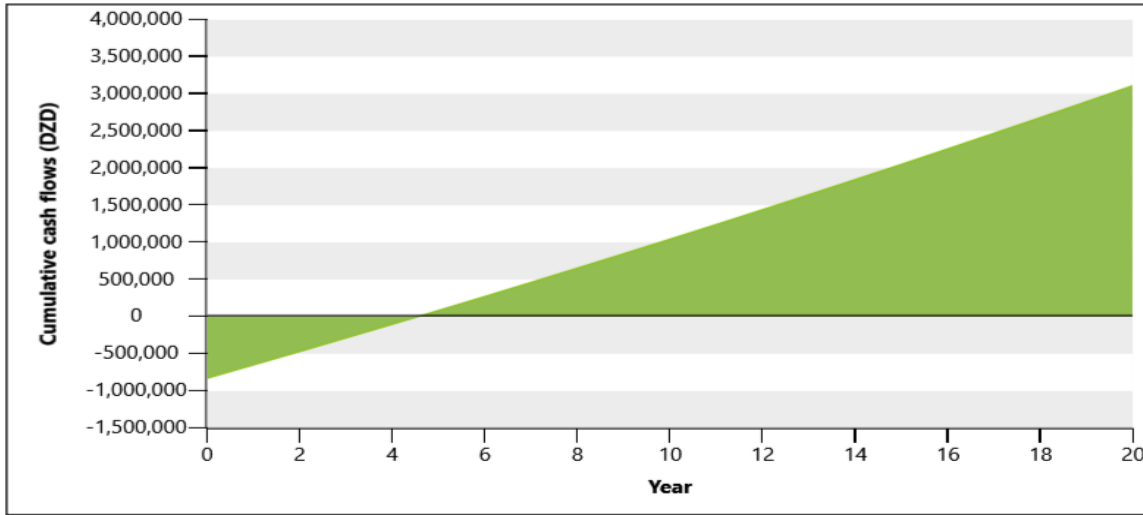


Figure 52. Project financial performance at full investment (Automation lab)

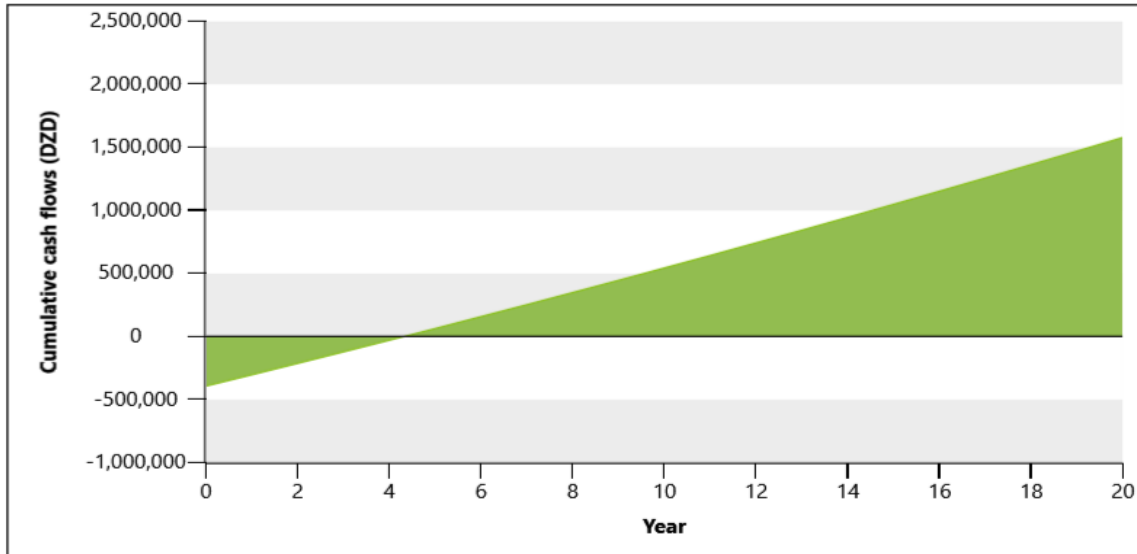


Figure 51. Project financial performance at low investment (Automation lab)

Table 32. Automation lab result

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	827,627	2%	20	4.7	3,111,699	22.1%
Low	391,520	2%	20	4.4	1,579,250	23.5%

- **General Laboratory**

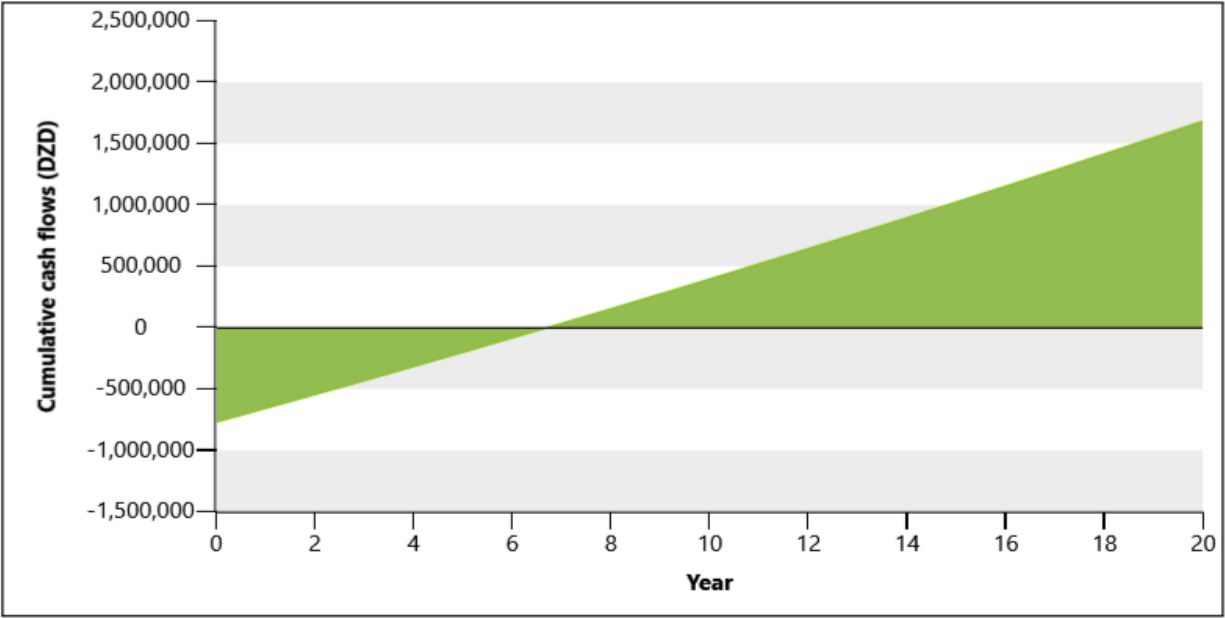


Figure 53. Project financial performance at full investment (Laboratory)

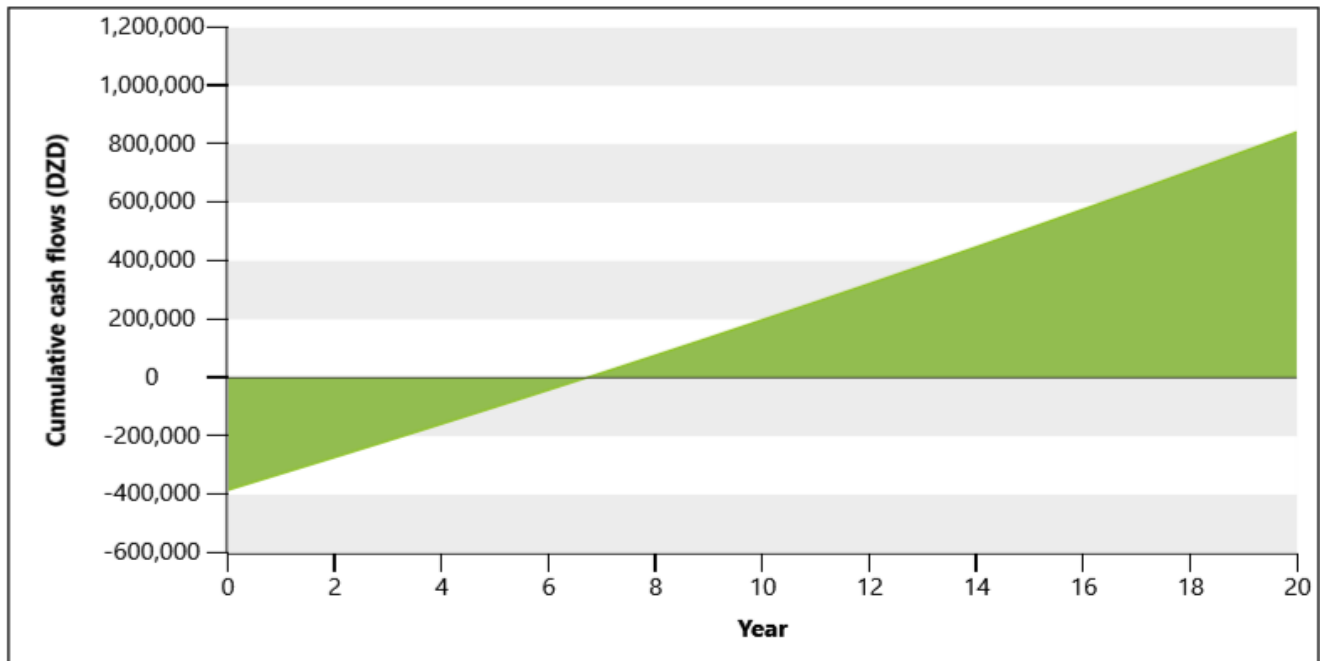


Figure 54. Project financial performance at low investment (Laboratory)

Table 33. General laboratory result

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	768,366	2%	20	7	1,684,247	14.3%
Low	384,106	2%	20	7	842,865	14.3%

Lecture Halls

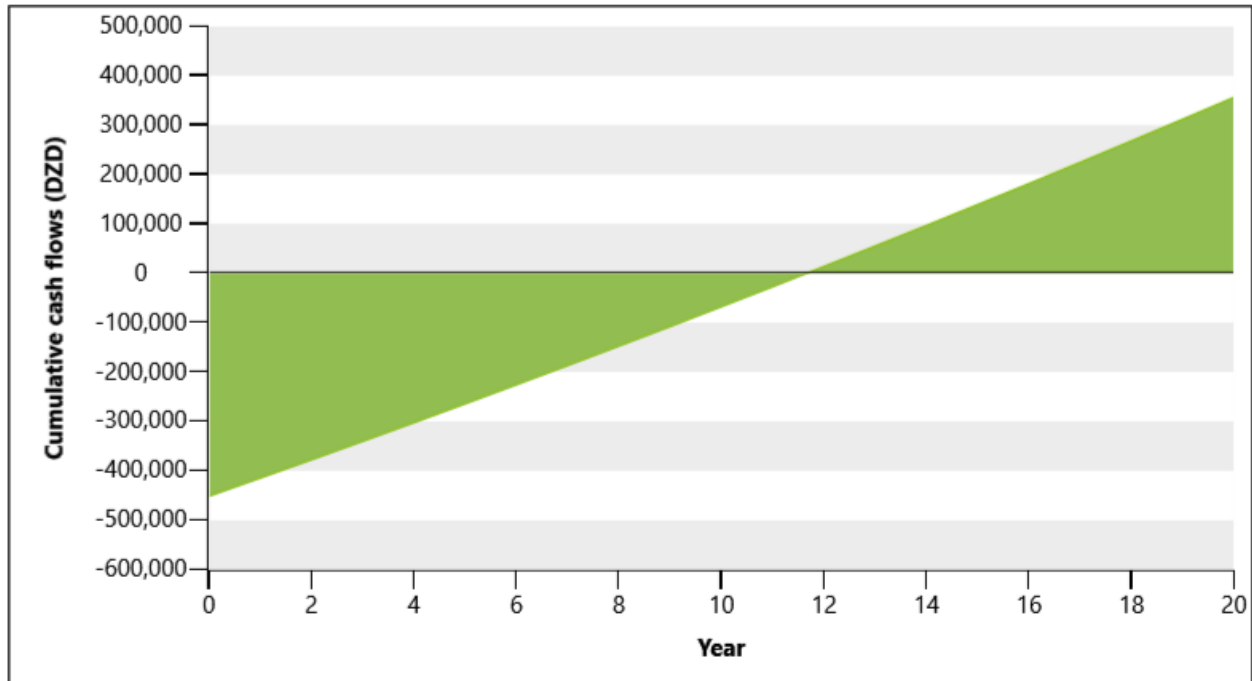


Figure 55. Project financial performance at full investment (Lecture Halls)

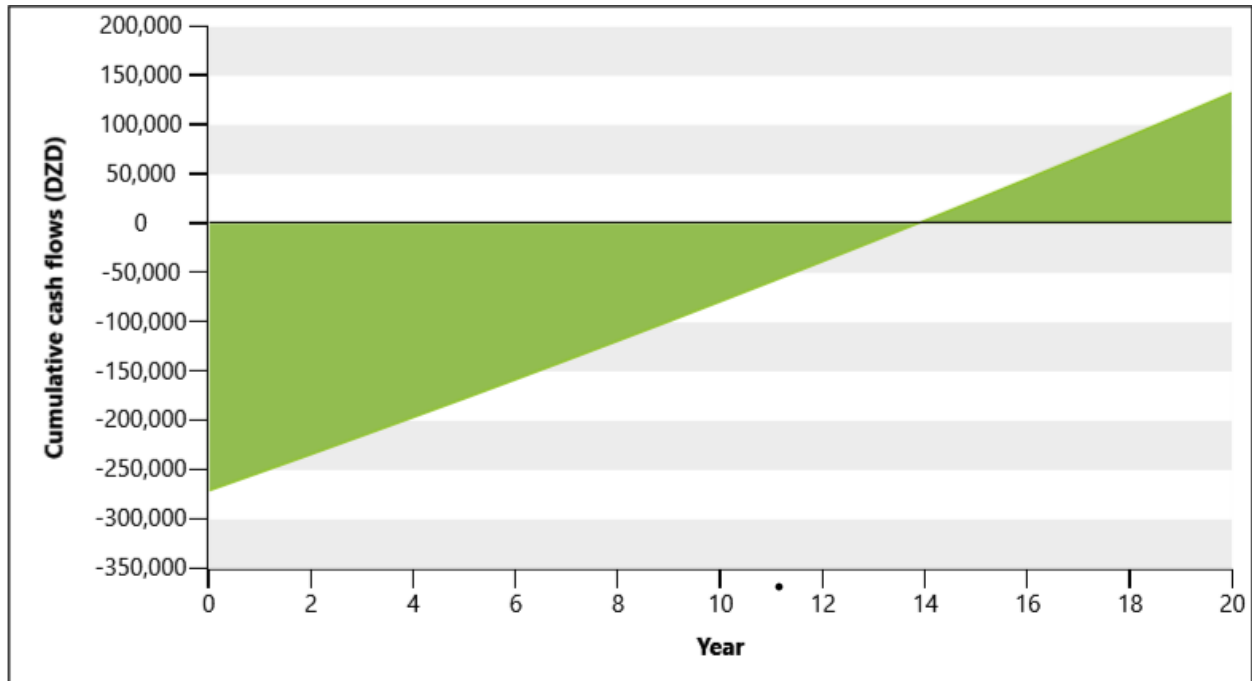


Figure 56. Project financial performance at low investment (Lecture Halls)

Table 34. Lecture halls result

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	451,147	2%	20	12.4	356,099	6.1%
Low	270,808	2%	20	14.9	166,564	4.0%

- **Library**

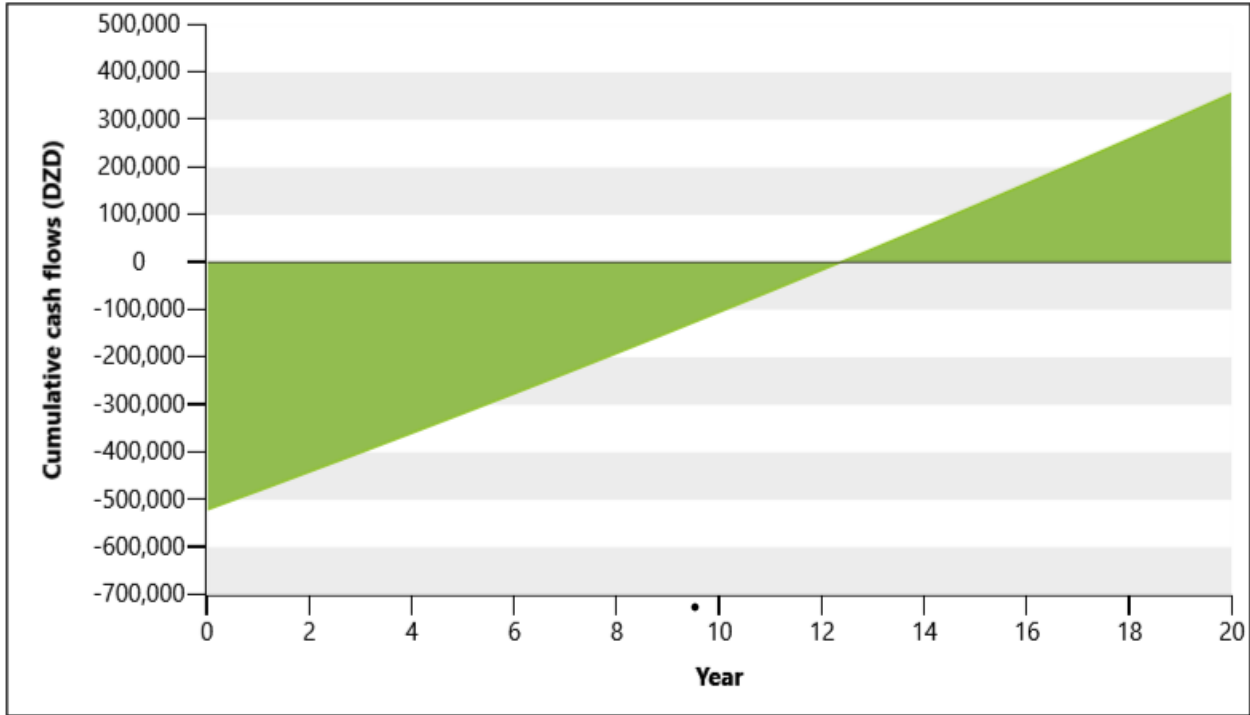


Figure 57. Project financial performance at full investment (Library)

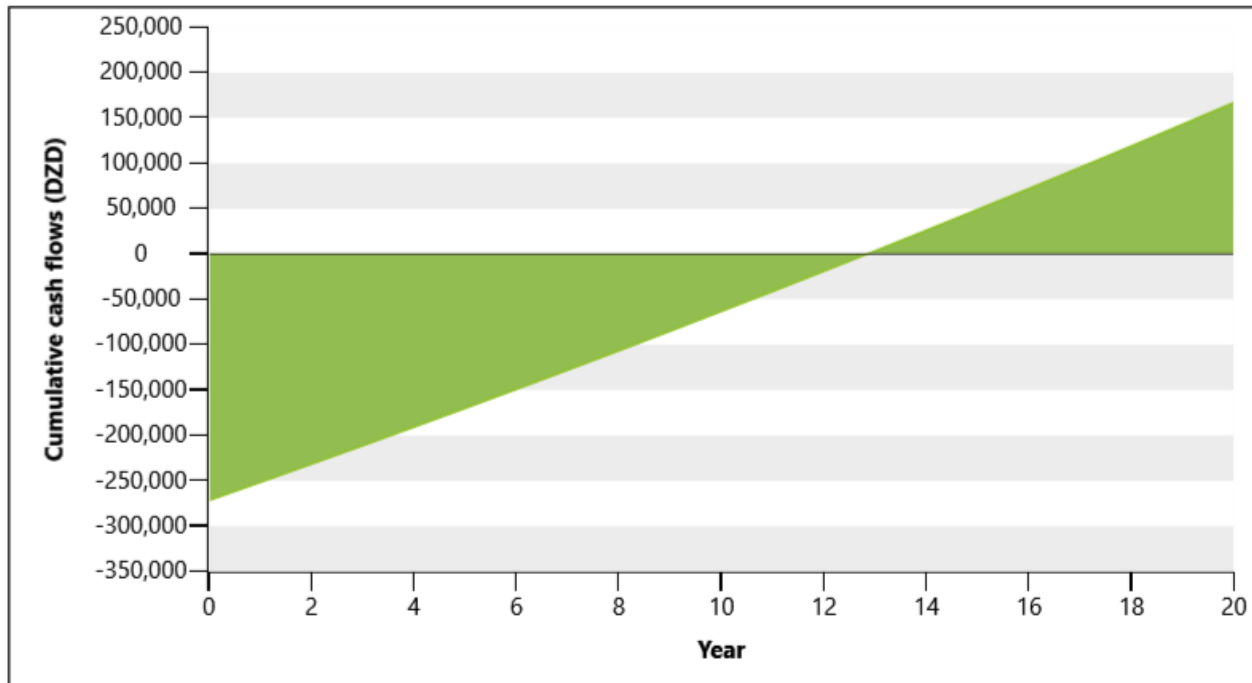


Figure 58. Project financial performance at low investment (Library)

Table 35. Library result

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	520,959	2%	20	13.2	355,838	5.4%
Low	271,556	2%	20	13.8	167,094	4.9%

- **Mechanical department**

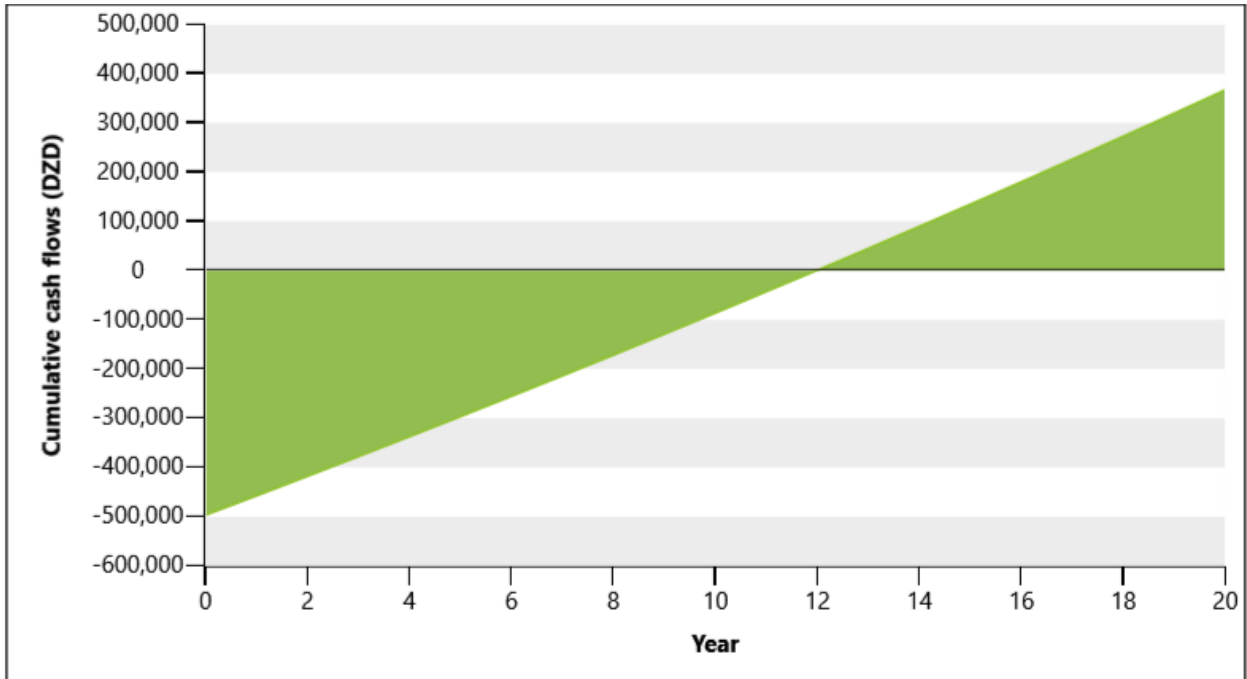


Figure 59. Project financial performance at full investment (Mechanical department)

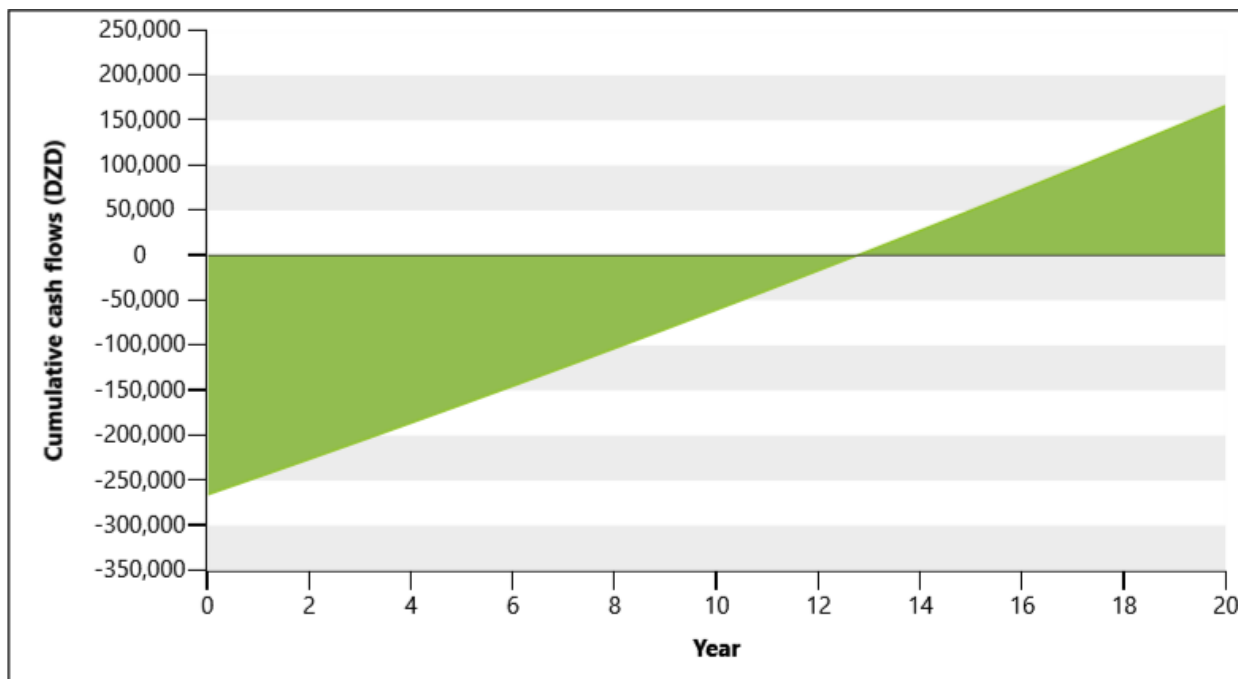


Figure 60. Project financial performance at low investment (Mechanical department)

Table 36. Mechanical Department result

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	496,833	2%	20	12.8	367,204	5.7%
Low	265,716	2%	20	13.7	166,564	5.0%

- **Architecture**

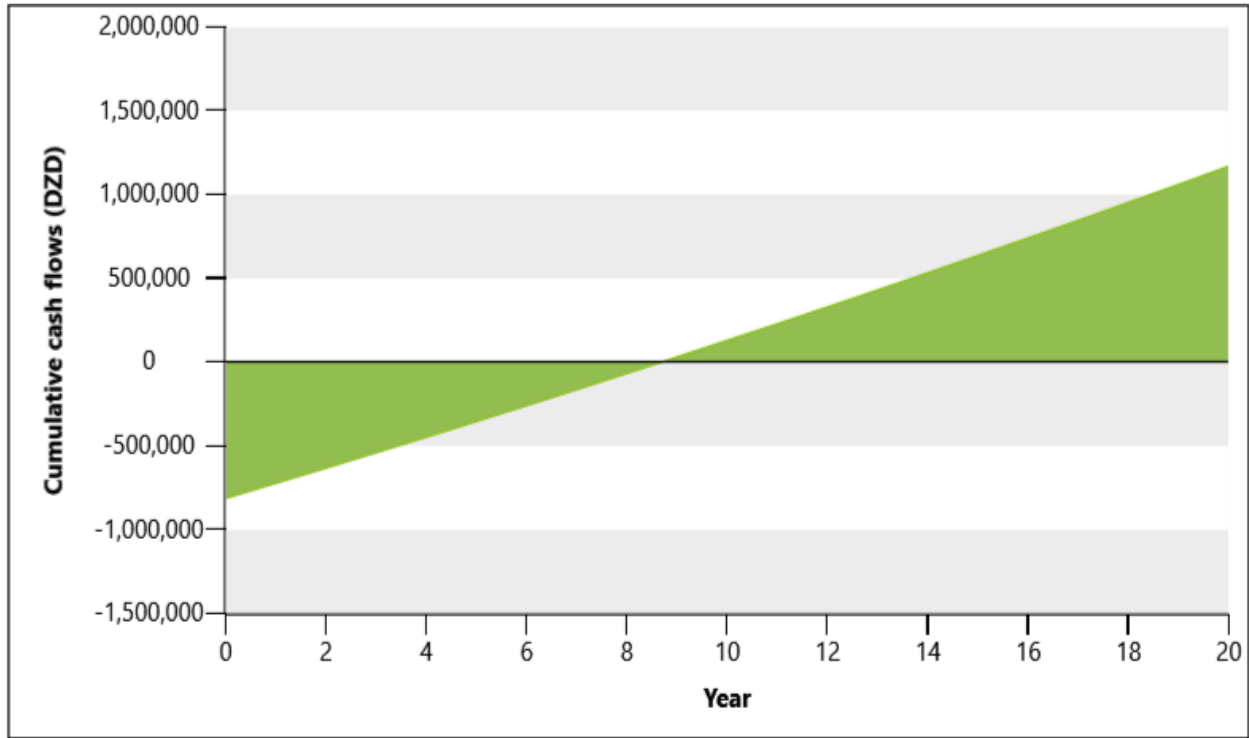


Figure 61. Project financial performance at full investment (Architecture)

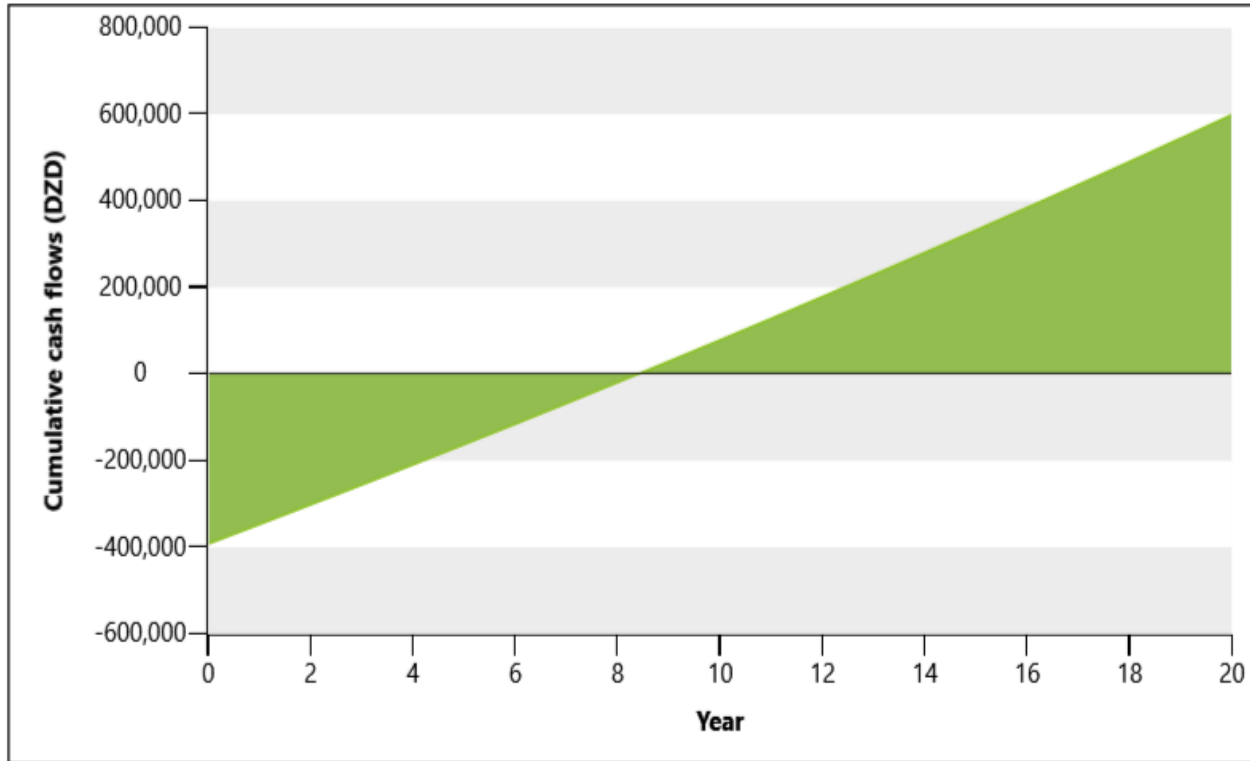


Figure 62. Project financial performance at low investment (Architecture)

Table 37. Architecture result

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	810,274	2%	20	9.1	1,169,743	10.1%
Low	391,790	2%	20	8.8	598,792	10.6%

- **Technology Hall**

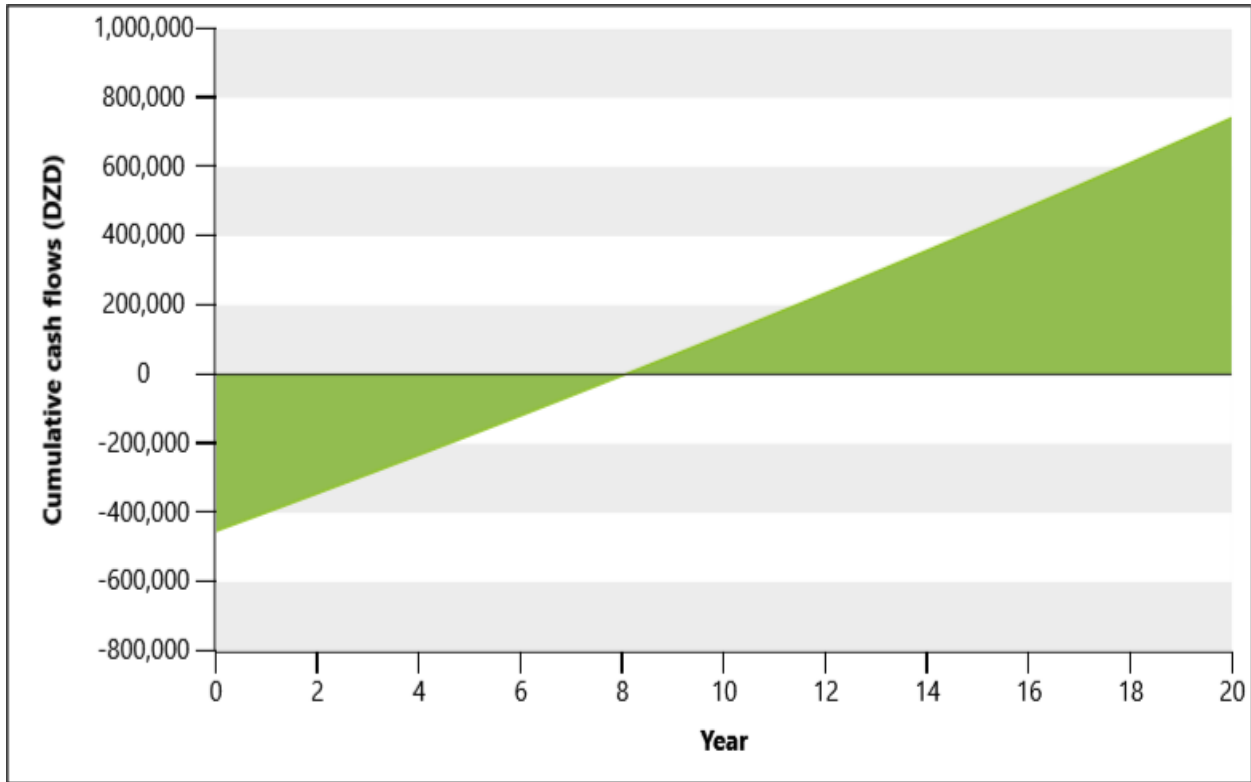


Figure 63. Project financial performance at full investment (Technology Hall)

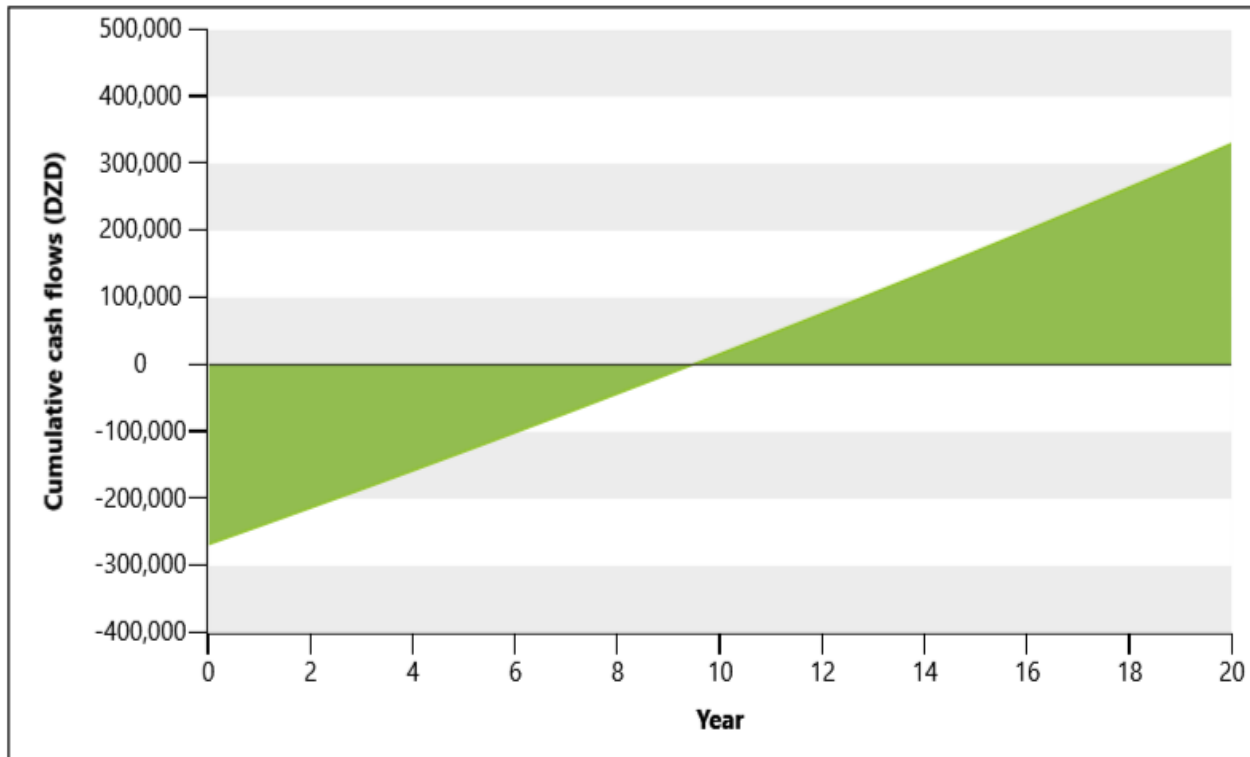


Figure 64. Project financial performance at low investment (Technology Hall)

Table 38. Technology hall result

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	452,602	2%	20	8.4	742,714	11.3%
Low	267,928	2%	20	10	330,093	8.9%

- Security Office

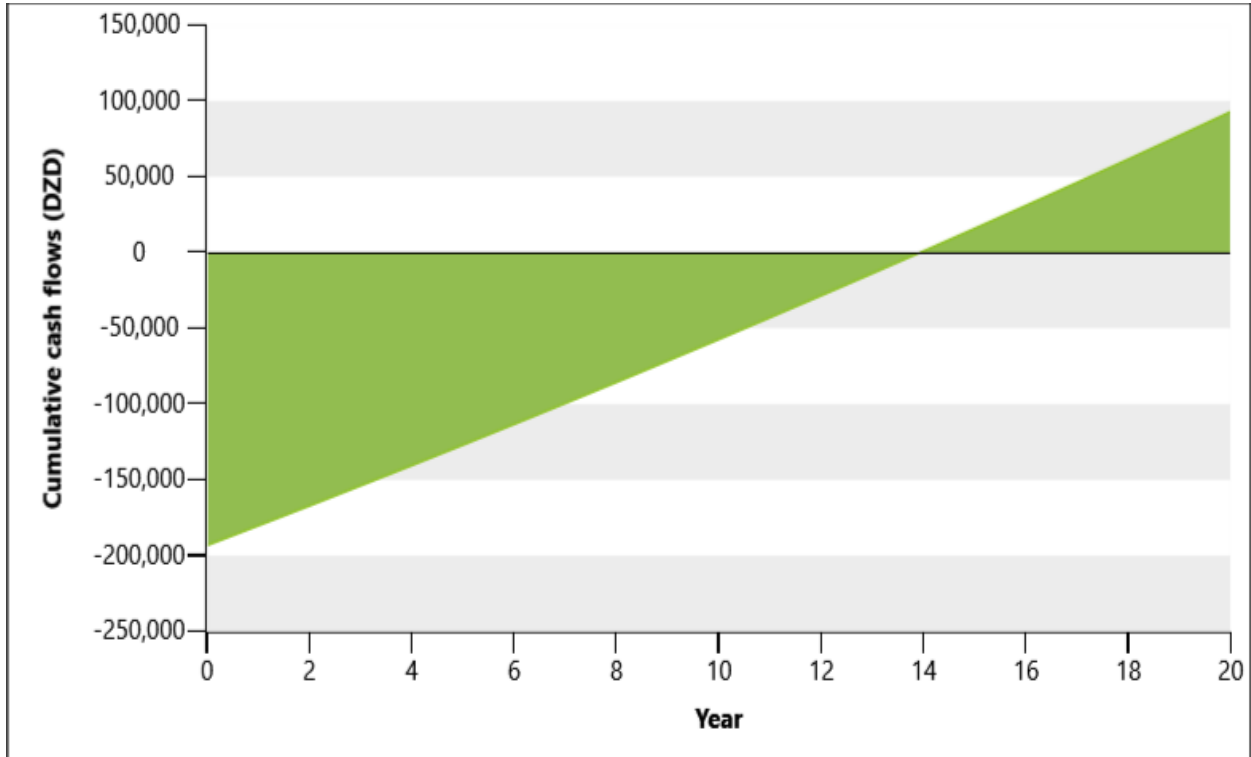


Figure 65. Project financial performance at full investment (Security Office)

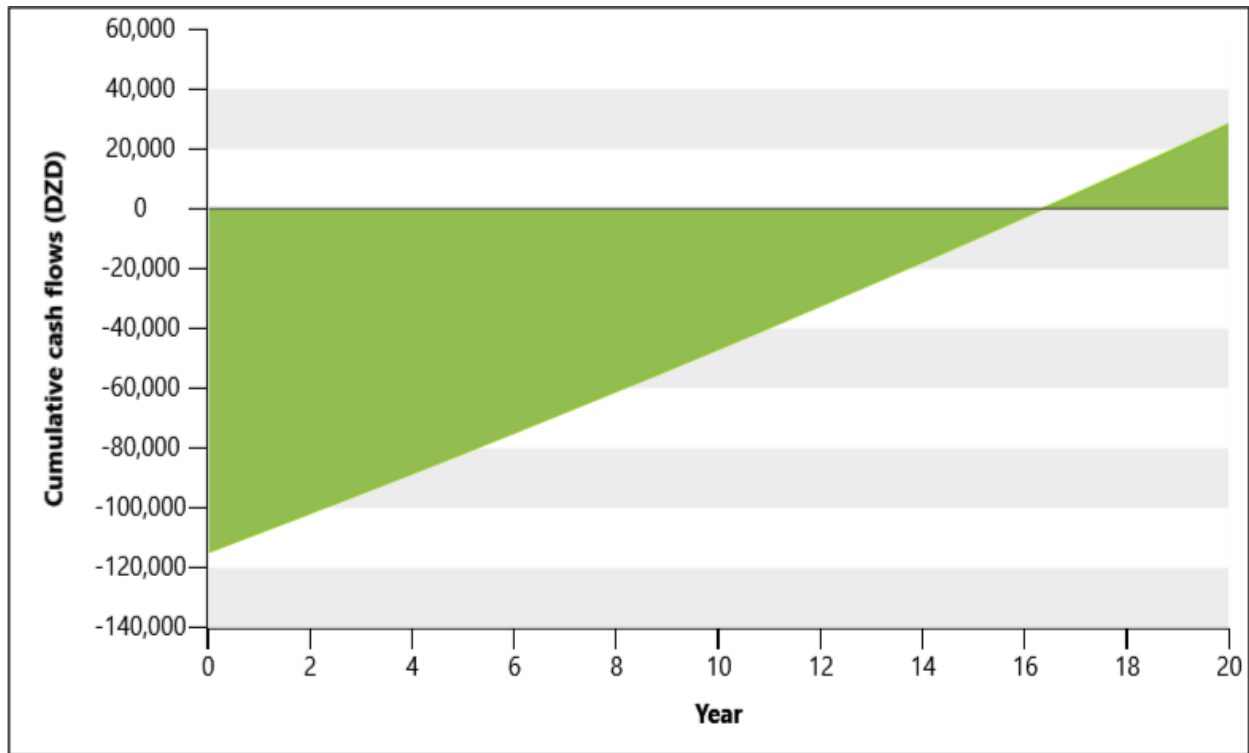


Figure 66. Project financial performance at low investment (Security Office)

Table 39. Security office result

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	193,172	2%	20	15	92,930	3.9%
Low	114,676	2%	20	17.8	330,093	2.1%

- **Conference Hall**

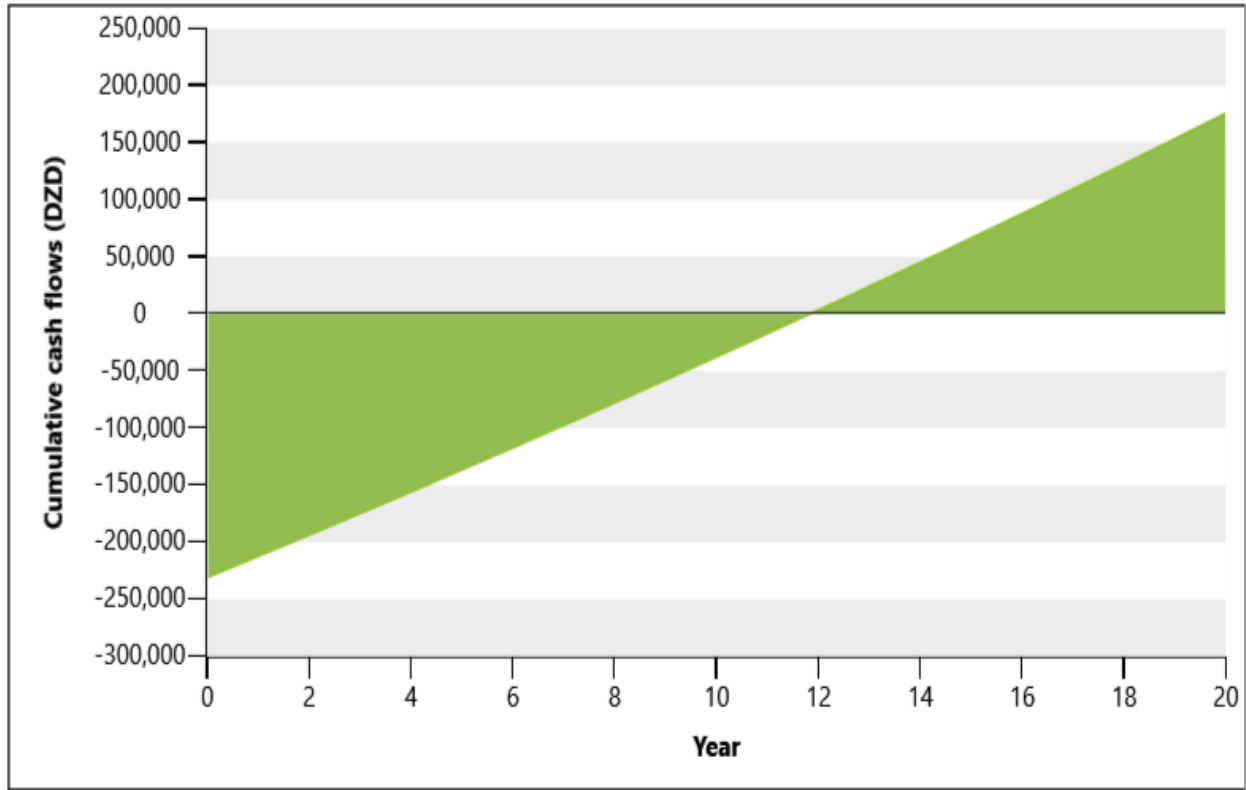


Figure 67. Project financial performance at full investment (Conference Hall)

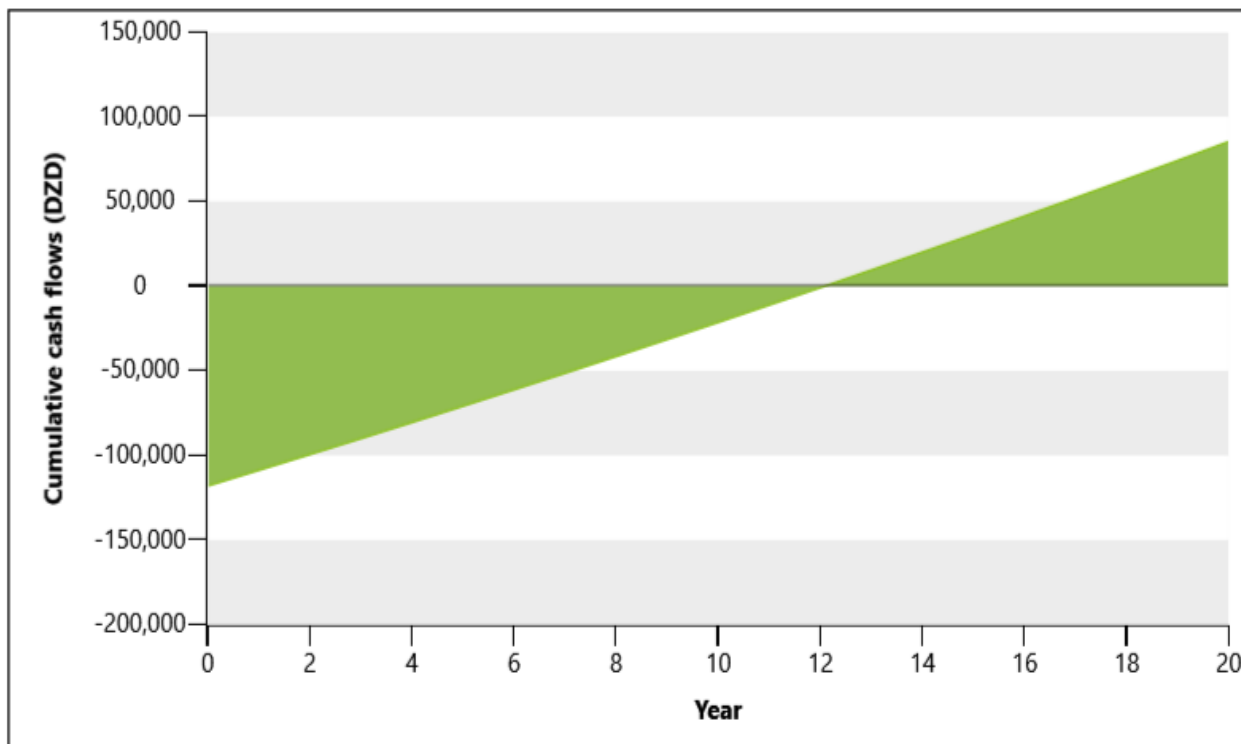


Figure 68. Project financial performance at low investment (Conference Hall)

Table 40. Conference Hall result

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full	230,732	2%	20	12.6	175,889	5.9%
Low	118,000	2%	20	12.9	85,413	5.6%

4.5 Retscreen results campus-wide

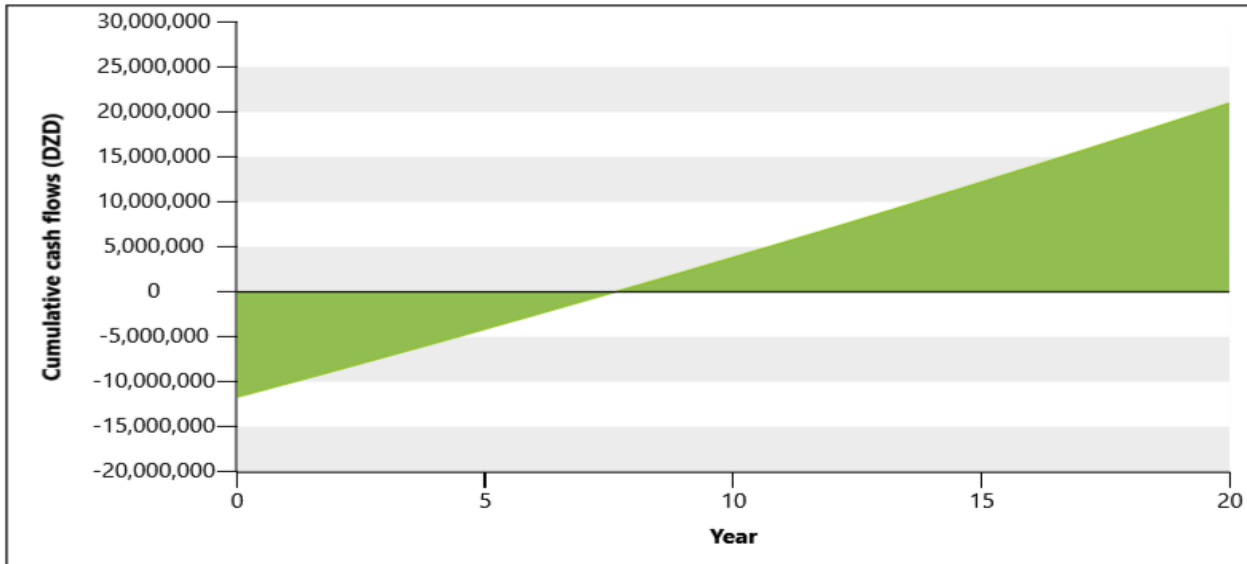


Figure 69. Project financial performance at full investment (current tariff)

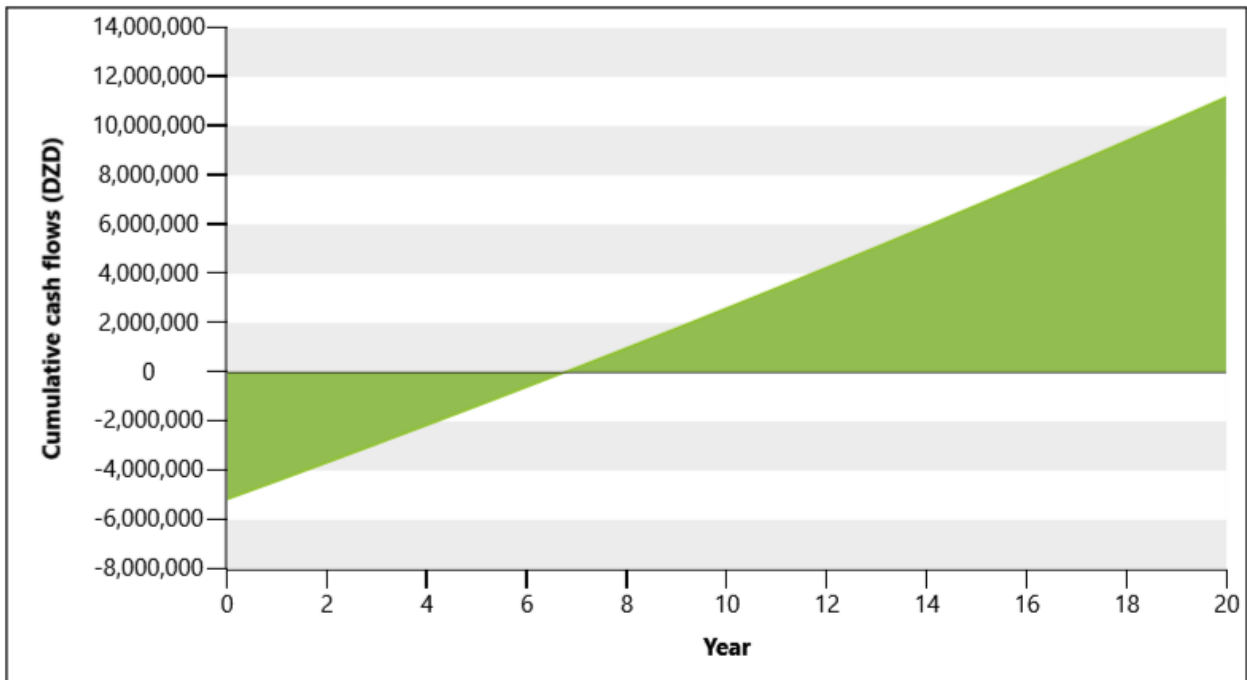


Figure 70. Project financial performance at low investment (current tariff)

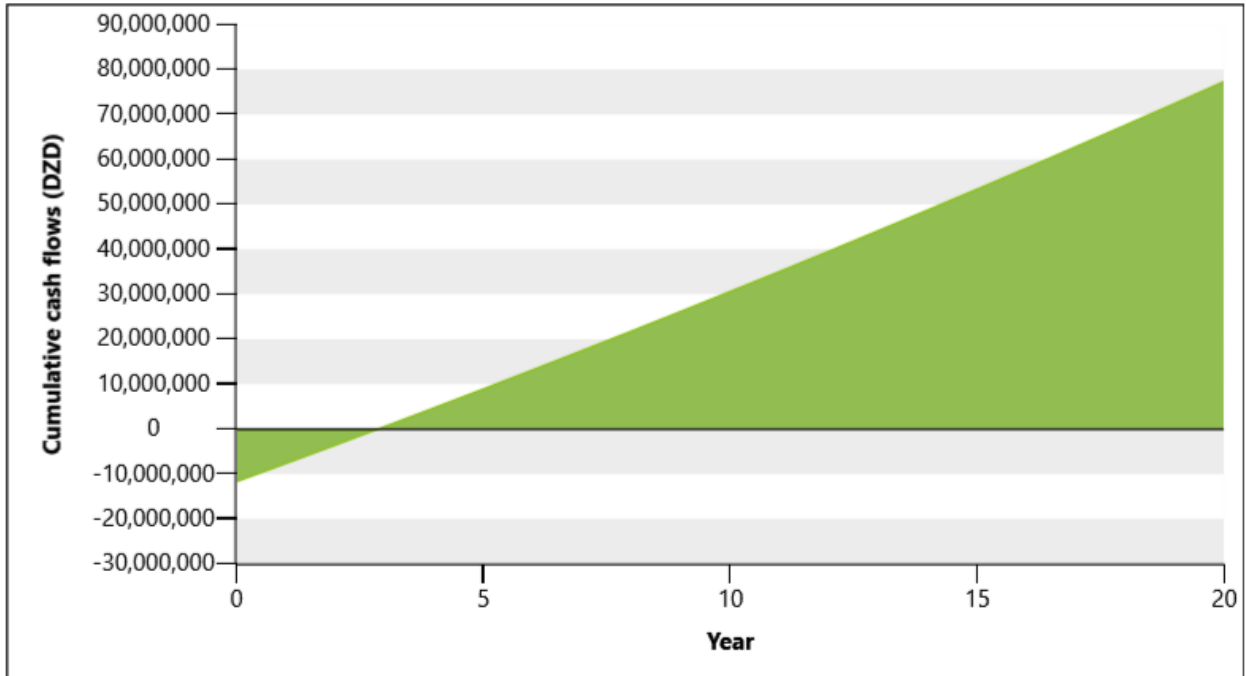


Figure 71. Project financial performance at full investment (future tariff)

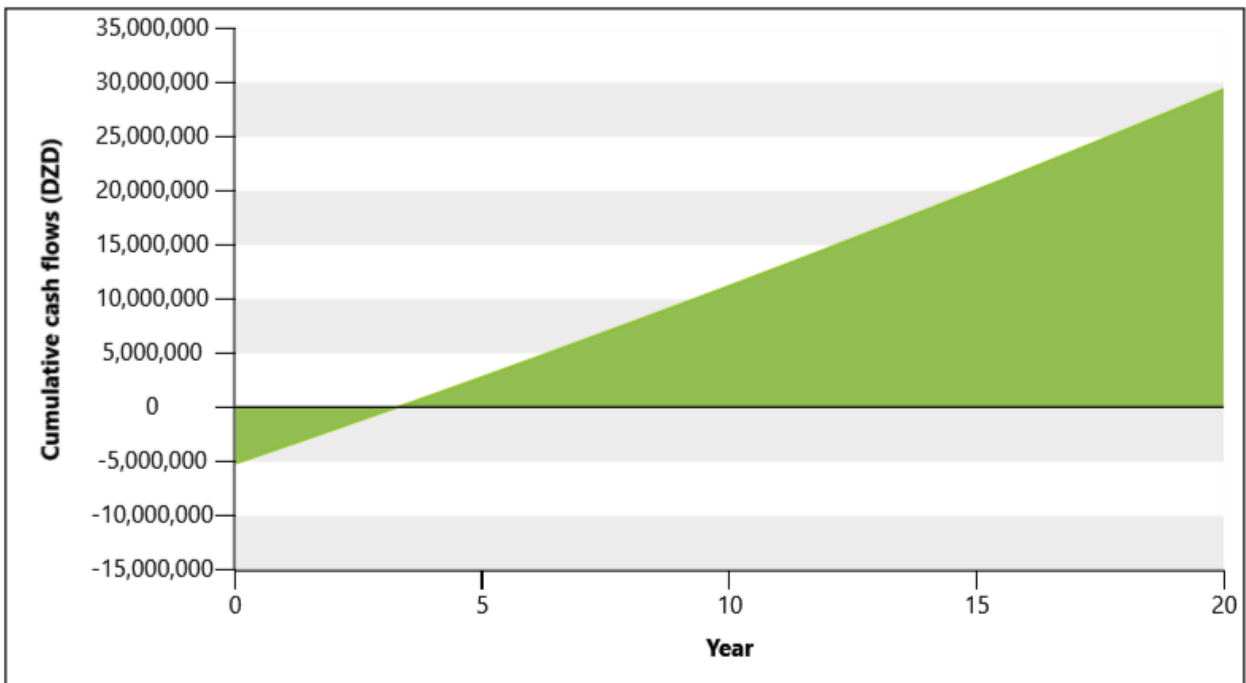


Figure 72. Project financial performance at low investment (future tariff)

Table 41. Campus-wide results

Type	Total investment (DZD)	Inflation rate	Project life	simple payback (yr)	Net profit (20 years)	IRR
Full (current tariff)	11,683,973	2%	20	7.9	21,004,688	12.1%
Low (current tariff)	5,163,189	2%	20	7	11,190,273	14.1%
Full (future tariff)	11683973	2%	20	2.9	77366296	35.5
Low (future tariff)	5163189	2%	20	3.3	29436416	31.3

We applied these measures on all financial performance projects:

- 20 years project life
- 2% inflation rate
- 1% Fuel cost escalation rate
- 3% discount rate

Conclusion

In this chapter, we calculated the annual amounts paid by the faculty for electricity and natural gas consumption, as well as the additional costs associated with upgrades from the current baseline to improved performance levels. These also include the extra expenses required for implementing the proposed energy efficiency measures. we calculated costs, return on investment, and savings for e ach building using the RETScreen software.

General Conclusion

This study set out to conduct a comprehensive energy audit of the Faculty of Technology at the University of Tlemcen, with the objective of assessing its current energy performance, identifying inefficiencies, and proposing cost-effective energy conservation measures (ECMs). In a context of rising energy demand and growing environmental concerns, the project contributes to Algeria's national strategy for sustainable energy management and to the global transition toward low-carbon buildings.

The research was carried out according to recognized international standards, particularly the EN 15217 and ISO 52000 series for building energy performance evaluation. The audit process was divided into three main phases: pre-audit, audit execution, and post-audit. The pre-audit phase established the baseline through utility data collection and stakeholder consultation. The audit phase combined field inspections, thermographic analysis, and quantitative modeling. The post-audit phase focused on reporting findings, proposing measures, and assessing their technical and financial feasibility.

The methodology integrated both analytical and simulation tools. Empirical data from SONELGAZ bills (2022–2024) were used to establish annual energy consumption trends for electricity and natural gas. Regression analysis based on heating degree-days allowed the separation of base and heating loads, providing an objective assessment of weather-dependent consumption. Complementary thermal imaging identified key areas of heat loss and infiltration, while RETScreen Expert software enabled quantitative evaluation of ECM performance under various investment and tariff scenarios.

The results confirmed that the Faculty of Technology has low to moderate energy efficiency, corresponding to an energy class between D and E according to EU benchmarks. Total energy consumption ranged between 5.1 and 6.2 million kWh per year, with heating accounting for more than 90% of total energy use. Electricity represented roughly one-third

of financial expenditures, despite its smaller share in physical energy, due to its higher tariff cost.

Regression modeling demonstrated a strong correlation ($R^2 = 0.75$) between energy use and climatic variation, confirming that heating demand is the dominant driver of consumption. The average annual base load was approximately 516 MWh, while the heating load reached 5.2 GWh. The analysis by block revealed that teaching blocks (A–C) were the largest absolute consumers, while laboratories and workshops exhibited the highest specific intensities, exceeding 300 kWh/m²·yr in some cases.

RETScreen simulations confirmed the technical feasibility and financial viability of the proposed package. Under the current subsidized tariff conditions (electricity = 5 DZD/kWh; gas = 0.6 DZD/kWh), the full investment scenario (\approx 11.7 million DZD) yielded an average simple payback period of 7.9 years with an IRR of 12.1%. The low-investment scenario (\approx 5.2 million DZD, excluding glazing and control system) provided an even shorter payback of 7 years and an IRR of 14.1%.

When analyzed under future tariff projections (electricity = 8 DZD/kWh; gas = 2 DZD/kWh), both packages became highly profitable, with payback periods of 2.9–3.3 years and IRRs exceeding 30%. These results underline the strong potential of energy efficiency investments, particularly in anticipation of progressive tariff adjustments and stricter energy regulations.

This thesis demonstrates that systematic energy auditing is a powerful, low-cost pathway toward sustainable energy management in educational institutions. The Faculty of Technology's audit provided both quantitative and qualitative evidence that targeted retrofits can yield substantial energy, financial, and environmental benefits.

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