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Enhancing Energy Performance and Reducing Consumption at the University of Basilicata: A Strategic Approach Towards Compliance with the 2050 Energy Roadmap

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Abstract: The Energy Roadmap 2050 necessitates the active participation of all sectors—including energy, construction, industry, transport, and agriculture—in a transformative energy paradigm. Over the past decades, there has been a notable increase in energy-related regulations, directives, protocols, and communications, which underscore the urgency of infrastructure interventions. Intelligent networks and energy storage systems are recognized as pivotal elements in enhancing sustainability and efficiency. This study presents a comprehensive technical-managerial program aimed at improving energy performance and minimizing consumption at the University of Basilicata (UNIBAS) campus in Potenza, southern Italy. An initial energy audit identified various energy-saving techniques, while ISO 50001 standards were employed to facilitate the establishment of energy performance objectives and strategies for consumption reduction. A dynamic simulation model was developed to assess the potential integration of photovoltaic and solar thermal systems, in conjunction with heat pumps. An Energy Baseline was established to evaluate the impact of these technologies. The strategies proposed to optimize both technological and managerial practices for the major energy variables were examined, with the effects tracked over time using established energy performance indicators (EnPIs). An economic assessment of the proposed strategies was conducted to evaluate their viability. Communication initiatives aimed at enhancing awareness regarding light rationalization and systems shutdown represent immediate interventions, while more invasive efficiency improvements are classified as medium- and long-term strategies. Compliance with European and Italian legislation mandates advancements in building envelopes and distribution systems, as well as the incorporation of renewable energy sources for thermal and electrical applications, alongside automation of building-plant systems through smart grids and actuators. It is anticipated that experts in energy management processes will adapt and expand the planned actions to ensure the energy sustainability of the university throughout the period from 2022 to 2050.

Keywords: Action plan; Decarbonization; Energy audit; Energy management system; Energy sustainability

1 Introduction

The new governance at the EU level requires Member States to define their respective national energy and climate plans annually, which will be evaluated and monitored by the European Commission in order to achieve a low-carbon European economy by 2050 [1]. The Energy Roadmap 2050 [2], which is the most important document of the European Green Deal [3], constitutes a European regulatory framework of references and establishes a decarbonized economy as a long-term goal, to which all sectors must compete, the energy, that of construction, industry, transport, and agriculture, within an energy model based on fundamentally different principles and methods than the current energy model [4].

The adoption of standards, directives, protocols, and communications in energy field by the European Community and the European Parliament has seen a significant increase over the past decade, and the sector continues to grow rapidly.

The roadmap presented by the European Commission includes an explicit mention of the need for infrastructure-specific interventions. The development of intelligent networks and energy storage systems would be crucial to the creation of a more sustainable and efficient energy system.

The goal of this initiative is to develop an action plan for the energetic sustainability of the campus of the UNIBAS in Potenza, in southern Italy, in order to implement a technical-managerial program for improving energy performance and reducing consumption. An initial energy audit was conducted as a cognitive tool for the building's performance and as a means of identifying actions and interventions aimed at promoting the rational use of energy.

In summary, the regulatory background on which the study and actions are based, as well as the evidence given in this paper, is:

- Directive 2009/28/EC on Renewable Energy Sources, implemented in Italy by Legislative Decree 28/2011 [5];
- Directive 2010/31/EC on the energy performance of buildings [6] (in Italy, Legislative Decree 63/13 converted into Law 90/2013);
- UNI CEI EN 16247-part 1-2-5: 2012 [7, 8]: Energy diagnosis: general requirements, buildings, and energy auditor skills;
- UNI EN 16798-2:2019 [9]: Energy performance of buildings - Ventilation for buildings;
- UNI/TS 11300 [10] regarding the energy performance of buildings.
- UNI/TR 11775:2020 Report [11] specifies the various processes to be taken to construct an energy audit.
- Ministerial Decree of 10 September 2010 [12] concerning the National Guidelines for the authorization of plants powered by renewable sources;
- Directive 2012/27/EC [13] on energy efficiency (implemented with Legislative Decree 102/2014);
- Ministerial Decree of 15 March 2012 (Burden Sharing) [14] for the definition and qualification of regional objectives in the field of renewable sources;
- Directive 2018/2001/EC [15] (implemented in Italy with Legislative Decree 199/2021) on the promotion of the use of energy from renewable sources;
- Ministerial Decree of 6 October 2022, n.383 [16] about the national plan for the containment of national gas consumption and heating containment measures;
- Ministerial Decree 23/06/2022 [17] concerning minimum environmental criteria (CAM).

The ISO 50001 (Energy Management System) standard [18] established the energy management system concept. It aims to achieve a continuous improvement in the energy performance of organizations through the implementation of energy performance objectives and strategies for reducing consumption. Finally, the actions that can involve an improvement in the technologies used and/or management practices of the identified key energy variables, as well as monitoring the effects of the improvement actions over time through the development of EnPIs, have been evaluated. The solutions have been separated into those to be implemented in the short term, such as communication and awareness for the rationalization of lights/shutdown lights and systems, and those to be implemented in the medium and long term, which include the most invasive interventions, such as efficiency improvements. These solutions are then evaluated and remarked on an economic basis: building envelope and distribution systems, use of thermal and electric renewable energy sources, and automation (smart grids and actuators) of the building-plant system (Building Automation Controls) in accordance with European and local (Italian) directives and regulations [19].

The proposed Action for Energy Sustainability of University 2022-2050 is, however, only the first step of a program of actions that can be modified and expanded with the contribution and participation of the subjects that operate at various levels in the field of energy management process definition. More broadly, this paper aims to demonstrate to readers (not necessarily practitioners) that with an accurate preliminary energy diagnosis, it is possible to design (quantitative) solutions and (qualitative) best practices for the mitigation of energy consumption of complex levels of public and private buildings, contributing to the roadmap that would lead to an accomplishment of the objectives aimed at achieving the final goal. In fact, the case study and planned interventions are a small contribution to a better common future: guidance and encouragement.

The article develops as follows: right after this introduction, the first theoretical section follows, which describes the methodology and introduces the case study, with a brief reference to similar works in the literature. The section that comes next deals with implementing the described methodology to the case study, highlighting the main uncovered criticalities at the end. This is followed by a section on the identification of energy baselines and, as a result, the interventions envisaged for consumption mitigation, as well as terms of economic investment and payback period. The paper concludes with both broad considerations and specific comments on the case study.

2 Methodology: The Energy Audit

The energy audit is a structured and systematic approach aimed at identifying energy inefficiencies and areas for improvement within a building-plant system. This process involves multiple stages, each of which contributes to a comprehensive understanding of energy use, inefficiencies, and potential savings [20].

The primary goal is to assess both technical and economic aspects of energy consumption and to identify feasible interventions that can enhance overall energy performance.

The methodology followed in this energy audit consists of the following steps:

1. *Data collection and analysis*

The first step involves gathering detailed data on the building's geometric and thermo-physical characteristics, as well as the performance of its plant systems (e.g., HVAC, lighting, and energy distribution systems). Data on energy consumption were obtained through historical utility invoices and on-site measurements. This included assessing the thermal performance of the building envelope, insulation levels, and the operational efficiency of the heating and cooling systems.

2. *Energy use profiling*

A comprehensive energy use profile was developed to understand the distribution of energy consumption across different building systems. This profiling helps in identifying high-energy-consuming systems and specific areas where inefficiencies are likely to occur. The analysis also included time-of-use data to identify peak demand periods and assess how operational schedules influence energy use.

3. *EnPIs*

Key performance metrics were defined to evaluate the building's energy efficiency. These EnPIs were used to measure the energy intensity of various systems (e.g., kWh/m^2/year) and to establish a baseline for comparing the effects of future interventions. EnPIs were developed based on standard operating conditions, allowing for adjustments based on factors such as weather and occupancy levels.

4. *Selection and optimization of energy improvement measures*

The selection of energy-saving measures was based on a multi-criteria decision-making process. The potential interventions were evaluated for both their technical feasibility and economic viability. Measures included upgrading insulation, retrofitting lighting systems to LED technology, and integrating renewable energy sources like photovoltaics and solar thermal systems. Each intervention was assessed using a cost-benefit analysis, which included calculations of potential savings in terms of primary energy reduction, management costs, and the impact of available tax incentives and subsidies.

5. *Dynamic simulation and predictive modeling*

A dynamic simulation model was created to predict the energy savings that could be achieved through the proposed interventions. This model simulated the building's energy use under different scenarios, accounting for variables such as seasonal temperature fluctuations, occupancy patterns, and changes in system operation. Predictive modeling allowed for the optimization of measures, ensuring that the selected interventions provided the maximum energy savings while maintaining operational efficiency and comfort.

6. *Economic and environmental evaluation*

Beyond technical optimization, the measures were subjected to an economic assessment to determine their financial feasibility. This included calculating the Net Present Value (NPV), Internal Rate of Return (IRR), and payback period for each intervention. Additionally, an environmental impact assessment was conducted to quantify the reduction in carbon emissions and other environmental benefits resulting from the implementation of renewable energy technologies and efficiency improvements.

7. *Implementation strategy and monitoring*

Finally, a phased implementation plan was proposed to carry out the interventions in stages. Each phase was designed to minimize disruption to campus operations while maximizing energy savings. A monitoring system using advanced energy meters and smart grid technologies was also planned to track the performance of each measure over time, allowing for continuous optimization and adjustment based on real-time data.

This comprehensive methodology ensures that the selected energy-saving measures are not only technically sound but also economically viable and environmentally sustainable, aligning with the long-term goals of energy efficiency and carbon reduction.

3 Case Study Overview: Qualitative and Quantitative Information

UNIBAS departments are comprised of buildings with a medium level of technological complexity and diverse environments (classrooms, administrative offices, laboratories).

Specifically, the site under investigation is the "Macchia Romana" Campus in the north-eastern area of Potenza, Basilicata, Italy. The campus houses the majority of the university's scientific degree programs. The campus houses the majority of the university's scientific degree programs. In this area, there are also all the general services, including the university's Central Library, a cafeteria and a dining hall, a residence hall, and sports facilities. The area is well connected to both the main road network and the historic center of the city, which is accessible even without the use of a vehicle. The campus includes a main building with five sub-buildings, greenhouses belonging to the Department of Agriculture, a library, a technical compartment for technological systems, and parking areas. The campus dates back to the early 1990s as the year of construction. The main body rises no higher than five floors above the ground. The five sub-buildings differ primarily in terms of construction techniques, intended use, and functionality, as four distinct departments coexist on campus: Mathematics, Computer Science and Economics (DiMIE), Engineering (SI), Science (DiS), School of Agricultural, Forestry, and Environmental Sciences (SAFE), and Human Sciences (DiSU) [21]. Using Figure 1 as a reference, buildings F, D, C, and B, in a minimum part, also have ground-floor porches.

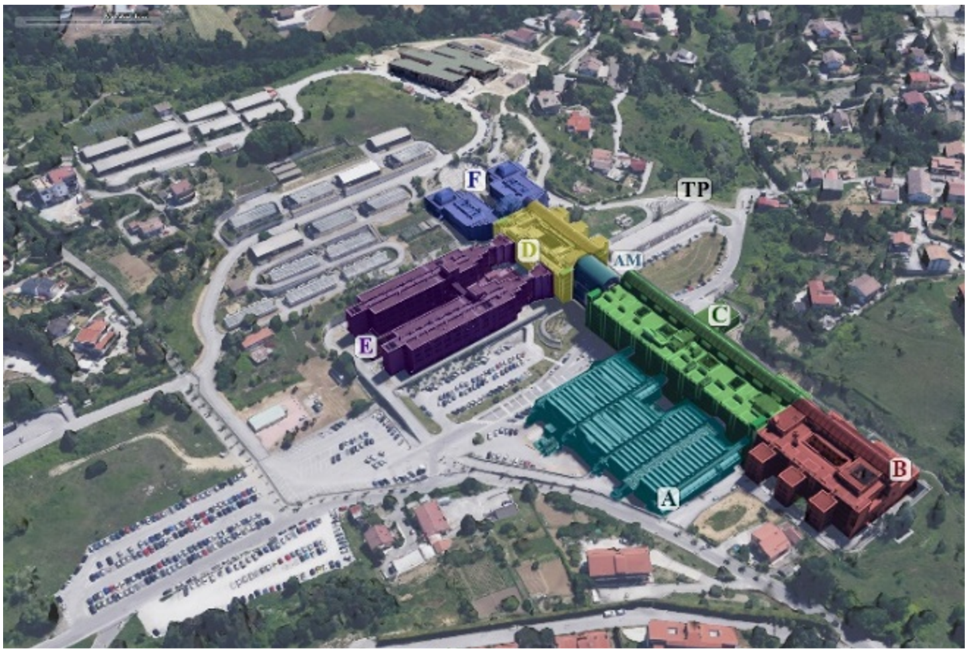

Figure 1. Aerial view of the Campus highlighting the sub-buildings under investigation
Note: This figure was prepared by the authors

From a climatic, geometric, and energy standpoint, the data in Table 1 are presented as follows.

Table 1. Climatic, geometric, and energy data of the campus

Climate Data		
Temperature days of the settlement region	2472	GG
Minimum design external air temperature	270.2	K
Maximum summer external air temperature	301.9	K
Climatic zone	E	
Wind speed	3.8	m/s
Wind zone	3	
Annual average temperature	12.6	$^\circ$C
Maximum horizontal summer solar radiation	26	$\mathrm{MJ/m^2}$
Minimum design extemal of the extemal air temperature	-3	$^\circ$C
Warm-up period	183	days
Annual average relative humidity	71.7	%
Geometric and Energy Data		
Thermal zone category (academic buildings)	E. 2	
Gross air-conditioned building volume (V)	502,983	$\mathrm{m^3}$
Gross dispersing surface area (S)	108,578	$\mathrm{m^2}$
S/V ratio	0,22	
Energy-efficient portion of the building	118,331	$\mathrm{m^2}$
Design value of internal temperature	20	$^\circ$C
Design value of indoor relative humidity	50	%

3.1 Literature Review and Similar Work

The wide range of recent publications in various journals highlights the multidisciplinary nature of this study field, demanding expertise across numerous areas. The literature presents a variety of auditing methodologies and energy-saving initiatives, focusing on distinctive ideas and building features. Many studies emphasize educational buildings, particularly school buildings and university campuses, due to their unique occupants, activities, and occupancy patterns, which pose specific challenges for energy efficiency and indoor environmental quality (IEQ).

Several studies have demonstrated innovative approaches to addressing these challenges. For instance, Allab et al. [22] conducted an energy audit on a French university campus, combining thermal comfort and indoor air quality (IAQ) issues. This transversal strategy gave them a comprehensive understanding of the building's operational conditions, particularly regarding occupant behavior and thermal comfort. Their findings echo those of many others, where occupant behavior plays a significant role in bridging the gap between calculated and actual energy consumption [23].

In contrast, a low-cost methodology was adopted by Mohamed et al. [24] in Jordan, where available data and resources were used for energy auditing without the need for expensive simulations. This approach demonstrated that practical and accessible solutions can be applied in resource-constrained environments, marking a shift from complex simulations to more pragmatic methods. Similarly, Semprini et al. [25] showed the potential for significant energy savings (32%) in a new engineering school building in Bologna, Italy, by focusing on enhancing heating system efficiency, indicating that even new buildings can benefit from targeted audits.

Kulkarni et al. [26] expanded this focus to crowded public buildings in India, where the dual objectives of understanding energy consumption and promoting rational resource use were emphasized. The importance of community awareness and participation in achieving energy efficiency was underscored, contrasting with the more technical, data-driven approaches of other studies.

Corrado et al. [27] provided an alternative perspective by actively considering external heat inputs as dynamic contributions in their energy audit of a school in Turin. This case is particularly intriguing because it aimed to transform the school into a nearly zero-energy building, distinguishing it from other studies in its ambition and scope. In Malaysia, Muhammad [28] similarly addressed energy inefficiencies in university accommodations but highlighted the financial burden of high energy consumption on institutions, stressing the need for energy efficiency policies.

Shcherbak et al. [29] took a more analytical approach, using multivariate and cluster analysis for a Ukrainian university audit. Their study pointed to poor resource management and irrational energy use as primary factors affecting the energy balance, suggesting that management practices are as crucial as technological upgrades.

Another interesting work conducted by Al-Othmany [30] integrated energy audits with sustainability protocols, particularly LEED certification in the United States. This approach provided a roadmap for energy-efficient interventions that align with global sustainability standards.

In comparison to these international examples, Italy faces challenges in the widespread application of energy auditing practices. Cardinale et al. [20] combined dynamic energy diagnoses with Life Cycle Assessment (LCA) to identify optimal design options for historical public buildings in Italy. Their work highlighted the need for sustainable interventions that not only conserve the architectural heritage but also reduce emissions and energy consumption. Additionally, Magrini et al. [31] emphasized the scarcity of local case studies and the need for more comparative analyses of Italian buildings. They proposed a grading system for assessing renovation needs, a suggestion that could be further explored to establish local benchmarks. Although several Italian studies have made strides in this field, as the literature indicates, there is still a notable gap in the availability of practical applications and recent case studies, particularly when compared to other countries.

This comparative analysis reveals that while numerous methodologies and interventions have been developed internationally, gaps remain in local and regional applications. It also highlights the importance of integrating both technological and behavioral approaches in energy audits, particularly in educational settings. The diversity of methods and outcomes from different geographical regions further underscores the need for context-specific solutions tailored to the unique challenges of each environment.

3.2 Case Study Preliminary Energy Audit

A preliminary energy audit was conducted as a tool for understanding the performance of the buildings and as a method for identifying the actions and interventions intended to promote the rational use of energy.

The diagnosis is based on an analysis of the current state, which, beginning with the standard reference conditions, continues with "tailored rating" modelling until it reaches the operating conditions, which simulate improved plant management and operation. The evaluation of excellence is based on the search for congruence.

The current state of art is described briefly below, and only the most significant results and critical issues are highlighted.

- Bearing Structure: Mixed reinforced concrete, steel.
- Technological Plant System: The campus is currently fueled by a methane-powered central heating system. The heating plant is housed in a dedicated room on the ground floor of the structure designated as the heating plant (TP in Figure 1). The thermo-cooling facility consists of four boiler heat generators powered by methane gas. Two generators with a useful power of 2,907.50 kW and two generators with a useful power of 3,000 kW have a maximum efficiency of 97%. Each heat generator supplies a distribution manifold located in the substation via its own pumping unit. Four double-walled insulated stainless steel flues discharge combustion by-products through stainless steel flue fittings. The average annual consumption of methane gas is approximately 790,000 m^3, which fluctuates depending on the season and operating hours. Three air-water heat pumps are installed for

cooling, two with a nominal power of 1.020 kW and an EER of 3.650 and the third with a nominal power of 487 kW and an EER of 3.650.
The terminals are water fan coils with a nominal thermal output of 7,303.80 kW.

- Plants From Renewable Sources: The self-production of electricity is attributable to the photovoltaic system and the cogeneration plant. The designed photovoltaic system is comprised of 2,259 monocrystalline silicon panels and 950 amorphous silicon panels and has a peak power of 773 kWp. The self-production is also supported by a trigeneration plant, which consists of an endothermic engine powered by methane gas and capable of producing electricity in the winter and hot water (to support the boilers) and electricity and chilled water in the summer.
- Opaque Envelope:
o Sub-buildings C-D-F: The walls are full-height sandwich panels composed of two layers of aluminum laminate sandwiching a 1 cm thick polyurethane panel. In reality, the walls are predominantly traversed by anchored fixtures. The profiles are clad in aluminum sheets of the same RAL color as the frame.
o Laboratories (sub-building A): Currently, the envelope is not insulated externally, but it is insulated internally with match boarding on both sides and mineral wool. The exterior cladding is a 2-centimeter-thick wooden panel.
o Attic of the porches: Sub-buildings C, D, and F are distinguished from the others by the development of a poarch with double inter-floor height (ground floor and first floor), allowing the passage of the road. Both the second and third floor attics are constructed from reinforced concrete slabs. without insulation and with an exposed bottom.
o Roof slabs of sub-buildings B-C-D-E-F: the package includes a reinforced concrete roof slab, a waterproofing layer, and a 3 cm grit concrete floor.
- Transparent Enevelope: The exterior fixtures are constructed entirely of pre-painted aluminum (no thermal break) and double-glazed 6-6-6 glass.
- Lighting: There are approximately 320 external mercury vapor bulbs and 1,000 internal neon lighting lamps with a ferromagnetic reactor. The existing ceiling lights are fitted with conventional FL (fluorescent) lamps ranging in power from 18 W to 54 W.

3.2.1 Main criticalities uncovered

- The open, uninsulated attics of the porches disperse heat from the heated rooms above, causing climatic discomfort for users, particularly during the winter months;

- The roof slabs of the remaining sub-buildings require extraordinary maintenance interventions, including those pertaining to the load-bearing structure; this causes significant heat loss, particularly in the nodes with vertical facades;

- Although the laboratory walls are internally insulated, this does not guarantee thermal functionality and energy savings;

- Due to climatic agents, the exterior wooden cladding of the heavy workshops has deteriorated significantly;

- Given that the greater dispersing surface of the vertical walls is due to the constant presence of full-height fixtures, there is a significant thermal dispersion, with resulting energy waste, largely due to the thermal bridges between metal panel fixtures and the formation of condensation;

- The heating system, and particularly the generators, do not provide for renewable energy sources;

- Currently, the ventilation system is an air-only system with constant pressure and temperature regulation. Due to the shape of the classroom, in order to achieve a comfortable temperature in the desk area (bottom), a high temperature is reached in the upper area, resulting in obvious discomfort for the classroom's occupants;

- The installed lamps are antiquated and do not utilize the most recent technologies. The installed lighting is inefficient in terms of energy consumption. However, they lack a suitable control system capable of dimming the luminous flux based on the visual task and any natural light contributions. Existing lighting systems are not outfitted with a consumption monitoring system that can report on the destination of electricity to the respective loads.

4 Energy Baselines

The energy consumption baselines encompass the annual and monthly usage of electricity and gas throughout 2022-2023. These baselines were measured in terms of tons of oil equivalents for thermal and electrical energy carriers, based on consumption data and associated costs, as detailed in Table 2. However, to substantiate the conclusions drawn from these baselines, a more in-depth analysis employing advanced statistical and modeling techniques is recommended. This could include regression analysis to identify trends, predictive modeling to assess the potential impact of interventions, and sensitivity analysis to understand the effects of variable changes on energy consumption.

The proposed energy improvement interventions for the university campus buildings are stratified into strategies with medium-short and medium-long-term benefits. These interventions are designed to align with environmentally friendly practices, utilizing materials and techniques that minimize environmental impact, as stipulated by the

Ministerial Decree 06/23/2022. The interventions prioritize rapid installation and low invasiveness, aiming to enhance the eco-compatibility of construction techniques while significantly reducing energy costs.

Table 2. Energy baselines outcomes (referring to 2023)

Energy Baseline (Sources)	Natural Gas	Electricity Supplied from the Mains	Electricity Self-produced on Site
Amount Consumed	1,140,000 Sm ^{3} /year	4,159 MWh/year	818.5 MWh/year
Amount Consumed in kWh/year	$10,754,717\mathrm{kWh}$ /year	4,159,011 kWh/year	-
CO_2 Emission Factor Value (Conversion)	0.1998	0.4332	-
CO_2 Emission per Baseline	2,148.79 (t/year)	1,801.68 (t/year)	-
Total CO_2 Emissions		**3,950.48 (t/year)**	

To provide depth to the analysis, statistical techniques such as time-series analysis can be applied to the energy baseline data to predict future energy consumption patterns and evaluate the effectiveness of the interventions. Additionally, data-driven predictive modeling could simulate various scenarios, offering insights into the potential outcomes of different strategic approaches.

The interventions not only aim at energy savings but also include renovations to improve the usability of internal and external spaces, particularly for students. A noteworthy project includes the installation of photovoltaic-paneled pergolas and the creation of a garden, which improve student spaces and enhance the quality of services offered by the university to the surrounding community. Furthermore, the redistribution and space recovery initiatives allowed for a comprehensive redesign of the campus's main entrance and parking facilities. The polycarbonate roofing over the main buildings' tunnel enables the rehabilitation of about 1,300 square meters below, optimizing these spaces for enhanced functionality and user experience.

4.1 Strategies with Medium-To-Long-Term Benefits

For the Campus of Macchia Romana, the planned works include:

- Technological Plants (redevelopment)
  - Redevelopment of the heating plant, including replacement of the two 2,907,60 kW heaters with two 3,000 kW high-efficiency boilers that may be combined with heat pumps. To serve each replaced generator, the supply and installation of anti-condensation electric pumps with a flow rate of 72 m^3/h and a head of 2 meters is planned. The new appliances will feature adequate safety systems, modulating gas burners with low pollutant emissions, and an electronic cam. They will be fully automatic (with a monobloc that can be rotated to the left or right) and equipped with an inverter and an O_2 regulation system. On both generators, anti-condensation pumps will be installed, existing chimney connections will be replaced, and the generators' water pipes and electrical power supply systems will be refurbished;
  - Replacement of air handling units with ventilation units that comply with the Erp Directive (the new ventilation units must save significantly more primary energy than they use to move air). The ultimate objective is to reduce the amount of energy lost or absorbed by ventilation systems in buildings;
  - Efficiency of distribution circuits (installation of variable flow pumps); for instance, attempting to choke the ventilation inside the classroom by ensuring to gradually close the ventilation channels with modulating motorized shutters, attempting to limit it in the upper area and leave it active in that of the teacher's desk. The created system can be managed on-site or remotely using the existing remote control and remote regulation technology.
  - For cascade operation, two two-way motorized valves will be installed on the hot water return pipes, one for each generator;
  - Integration of remote-control systems and energy monitoring of (summer and winter) air conditioning systems.
  - Fan coils already installed as terminals are not intended to be replaced.
- Plants from Renewable Sources: The portion of self-generated energy at the Macchia Romana complex should meet approximately 25% of the site's total electricity demand. But no integration of photovoltaic is foreseen in these interventions. Also, the trigeneration facility is not intended for change.
- Opaque Envelope

  o Laboratories (sub-building A): Replacement of the exterior wooden siding with insulated metal panels in 8 cm EPS self-supporting panel. The cladding will be completed with sheet metal work for the building's corner edges, fixtures, connection to the foundation, and vertical junction between the rows of panels. Together with the existing internal panel composed of two-sided match boarding and internal mineral wool, it will ensure thermal efficiency and energy savings;

  o Sub-buildings C-D: On the interior side, the construction of a 10-centimeter-thick EPS counter wall with an exterior coating of smooth, pre-painted aluminum sheet in the same RAL color as the existing sandwich panel.

The false wall will be attached to the steel uprights using screws. In addition, the fan coils will be relocated to a location adjacent to the newly constructed insulated false walls;

o Attic of the porches: The existing roof will be replaced with a 16 cm aluminum and rock wool insulation package;

o Roof slabs of sub-buildings B-C-D-E-F: A new roof slab will be installed with the necessary waterproofing to eliminate thermal bridges and condensation. Additionally, a 16-centimeter EPS insulating panel will be installed within the package layers.

- Transparent Envelope: The replacement or installation of new windows is not foreseen.

The Table 3 provides illustrative, but not exhaustive, comparisons between the transmittances of the actual state and those of the project.

Table 3. Transmittance comparison of interventions

Item Description	U.ante $\left[\mathrm{W/m^2K}\right]$	U.nost $\left[\mathrm{W/m^2K}\right]$	Isolation Location	Thickness [cm]
Insulated wooden wall	0.471	0.229	external	8
Insulated sub-window panel	1.704	0.291	internal	10
Attic of porches	2.669	0.229	external	16
Predalles roof-slab	0.911	0.156	external	16

4.2 Strategies with Medium-To-Short-Term Benefits

• Lighting: Replacement of traditional internal and external lamps with LED lamps, accompanied by the installation of an intelligent lighting management and regulation system (depending on the intended use, the number of occupants, etc.). The lighting system has a low energy footprint and a high level of efficiency; the project calls for extensive use of LED devices. The lighting systems were designed with the following factors in mind:

o Internal: All lamp types must have a luminous efficiency of 80 lm/W or higher and a color rendering index of 90 or higher.

o External: All lamp types must have a luminous efficiency at least equal to 80 lm/W and a color rendering at least equal to 80.

In general, the color temperature of the light sources will be 4000°K, resulting in a neutral light tone suitable for school environments.

• Automatization of Systems: The air distribution system's control system will include the DDC controllers necessary for the control and management of the dampers and the inverter on board the UTA. The regulator will command the progressive closing of the damper until it is completely closed when the upper area temperature detected by the room thermostat is exceeded. As the temperature falls below the predetermined threshold, the damper will reopen. The pressure sensors downstream of the supply fan and upstream of the return fan will transmit a pulse to their respective regulators, which will adjust the number of revolutions of each fan via the inverter. The air quality sensor will inhibit the action of the dampers by returning them to the fully open position if the air quality falls below the predetermined threshold.

All of the planned lighting bulbs are considered intelligent because they are outfitted with brightness smart drivers and an auto dimmer capable of dimming the artificial lighting in response to the amount of external light. In its own radio-controlled communication network, the new lamps will be wirelessly interfaced with the home automation control unit (one for about 500 lighting fixtures).

Figure 2 illustrates all planned interventions and the sub-buildings for which they are intended. The planned technological system modifications impact the entire complex.

4.3 Management Strategies

In light of the current energy crisis, which poses significant social and economic challenges, it is imperative to adopt an energy management framework that underscores environmental stewardship. This framework aims to immediately reduce and rationalize the energy consumption of UNIBAS. The following technical management measures exemplify the approach:

- Optimization of thermal plant operations: Strategically reduce the operational period of natural gas-fueled thermal plants during the 2022-2023 winter season to enhance energy efficiency.

- Precision temperature control: Lower heating temperatures by 1℃ in all spaces equipped with digital thermostats and activate the heating system based on occupancy, ensuring energy is used only when needed.

- Advanced temperature regulation: Install digital thermostats for precise temperature control and regulation in areas not currently equipped, enabling greater oversight of energy usage.

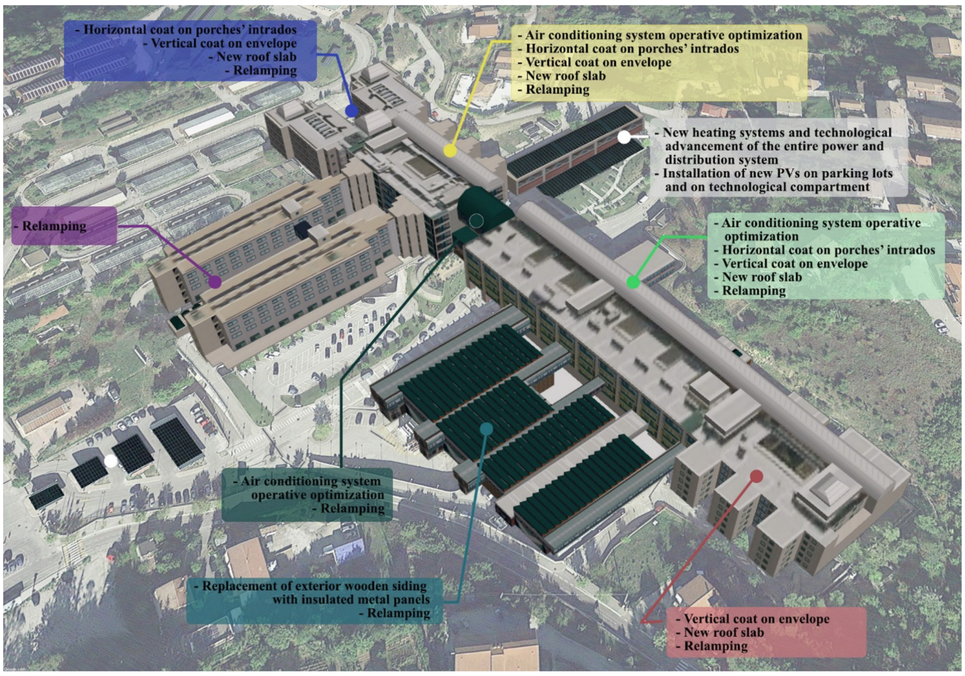

Figure 2. Designed interventions

Note: This figure was prepared by the authors

- Strategic system deactivation and reactivation: Implement night-time deactivation of heating bleed circuits to conserve energy and reactivate heat recovery units that were suspended during the COVID-19 pandemic, optimizing ventilation efficiency.

- Scheduled heating system operation: Reduce the daily operating hours of heating systems by 3.5 hours per week, ensuring alignment with actual needs and minimizing waste.

- Outdoor lighting optimization: Employ advanced technical and management measures to streamline outdoor lighting consumption, utilizing sensors and smart timing, and maximizing natural light wherever possible.

- Efficient elevator usage: Encourage rational use of elevators, especially minimizing short, energy-intensive trips, and promote stair use as a healthier and more sustainable option.

- Control of unauthorized heating devices: Prohibit the use of electric stoves and individual heat pump air conditioners unless critical, to prevent unnecessary energy consumption.

- Proactive light management: Promote a culture of energy consciousness by ensuring all lights are turned off when exiting offices and shared spaces such as bathrooms and hallways.

- Technological energy settings: Utilize energy-saving settings on computers, with automatic standby activation from keyboards or operating system features. Program monitors to turn off and hard drives to deactivate during inactivity, and ensure computers go into standby or shut down at day's end.

- Adaptive energy redistribution: Permit the dynamic local redistribution of surplus energy to neighboring areas facing deficits, optimizing campus-wide energy use.

- Dynamic load and storage management: Implement real-time management of energy loads and storage systems, continuously regulating generation for systems connected to national grids. Utilize smart grid technologies and actuators to enhance the automation of the building-plant system.

By integrating these best management practices, the university can achieve significant improvements in energy sustainability, aligning with both immediate goals and long-term compliance with European and Italian energy legislation. This strategic approach fosters a culture of conservation, proactively addressing the challenges of the current energy landscape while enhancing overall operational efficiency.

Figure 3 illustrates the comparison between the current energy class of the entire building as well as the amount of nonrenewable primary energy consumed by the entire building under study and the energy class of the entire building based on the proposed project interventions as a conclusion to this paragraph. Due to the fact that the system upgrades do not include the replacement of the generator and the project does not include heat pump systems, the mediumhigh and not excellent energy class is justifiable.

More specifically, when considering partial effects relative to the planned measures, the installation of thermal insulation reduces global primary energy by approximately 23% (of which 90% pertains to the reduction of non-renewable primary energy). The cost of this intervention accounts for about 47% of the total expenses. The replacement of window frames, impacting roughly 48% of the overall economic expenditure, results in a 6.5% reduction in global primary energy (98% of which is due to the reduction of the non-renewable portion). Finally, given the minimal modifications compared to the current state of the system infrastructure, the intervention on the systems has an economic impact of 5% on the total expenditure and indeed reduces global primary energy by just 2% (with a 35% impact on the non-renewable portion and 75% on the renewable portion).

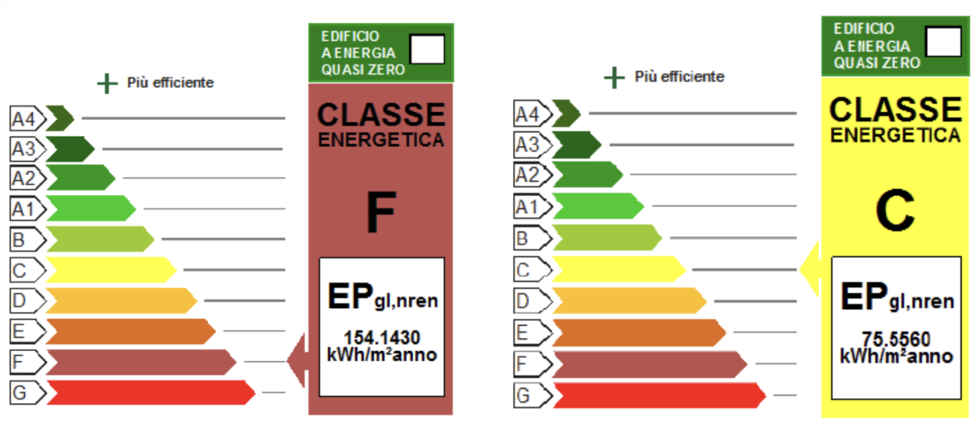

Figure 3. Comparison of Campus energy class before and after planned interventions

5 Economic Framework of the Proposed Interventions

The economic framework for assessing the proposed energy interventions involves a comprehensive evaluation of the financial implications, including both costs and expected benefits over time. This analysis is crucial for decision-making and prioritizing investments.

The analysis begins with the tailored rating method, which assesses potential technological and system improvements aimed at enhancing the building's energy performance. Part of this evaluation includes estimating the annual management and maintenance expenses associated with each system to ensure their long-term sustainability.

To calculate the economic viability of each intervention, several financial metrics are employed:

- *Payback Period*: This is determined by summing the costs of individual interventions within a scenario and comparing them with the cumulative savings generated over time. The payback period is reached when these savings surpass the initial investment, which for the proposed interventions is around the seventeenth year.

- *NPV*: This is calculated by discounting future cash flows to their present value and indicates the overall value added by the project. A trend reversal in NPV—where it becomes positive—signals that the investment is starting to generate net benefits.

- *IRR*: IRR is the interest rate that makes the NPV of all cash flows from the investment equal to zero. It is a critical threshold that helps in comparing the profitability of the investment relative to alternative opportunities.

- *Profitability Index (PI)*: The PI is calculated by dividing the present value of future cash flows by the initial investment cost. A PI greater than one indicates that the investment is expected to generate more value than its cost.

These metrics collectively offer a comprehensive understanding of the economic implications of the proposed interventions, aiding stakeholders in making informed decisions about where to allocate resources for maximum impact.

Table 4. Energetic and economic framework summary

Indicator	M.U.	Pre	Post	Variation (%)
Total Non-Renewable Primary Energy [EPgl.nren]	kWh/m^2	154.14	75.56	-50.98
Total Renewable Primary Energy [EPgl.ren]	kWh/m^2	27.57	27.32	-0.91
Global Primary Energy [EPgl.tot]	kWh/m^2	181.71	102.88	-43.38
Energy Production Cost	€	1,708,957.38	1,131,130.82	-33.81
CO_2 Emissions	kg/m^2 year	37.89	25.94	-31.54
Payback Time	years		17.6	
Total Cost of the Interventions	**€**		$\mathbf{8,510,913.16}$	

A cost-benefit analysis is conducted, taking into account energy baselines, which include parameters such as fuel prices and a discount rate set at 2 percent. Other key factors considered are the energy production cost, CO_2 emissions resulting from energy use, and the initial investment cost required for each intervention.

Table 4 contains the comparison table between the pre- and post-intervention indicators.

From the perspective of environmental impacts caused by CO_2 emissions, the value remains considerably high, despite a reduction of approximately 32% in emissions with the planned measures. This value is, however, justifiable considering the presence of four condensing boilers powered by natural gas, which alone account for 65% of the total CO_2 production. The portion of interventions concerning the system infrastructure, without undergoing significant changes, reduces CO_2 production by only 2% compared to the pre-intervention state. A significant improvement would be to replace the four boilers with high-performance heat pumps, but the total cost of the initial investments would be substantially higher, thereby increasing the overall payback period of the investments.

The evaluation of the payback time for the scenario in question was conducted by aggregating the costs of the individual measures of which it is composed. Similarly, incentives and financing defined for each of the individual measures were considered. The assessment of the investment payback time was carried out through cash flow analysis and corresponds to the reversal of the trend of the NPV. The following Table 5 shows the annual development of the investigation.

Table 5. NPV trend over the next 25 years

Year	Investment (€)	Non-discounted Cash Flows (€)	Cumulative Non-discounted Cash Flows (€)	Discounted Cash Flow (€)	Cumulative Discounted Cash Flows (NPV) (€)
0	8,510,913.16	-8,510,913.16	-8,510,913.16	-8,510,913.16	-8,510,913.16
1	0	577,826.56	-7,933,086.60	566,496.63	$-7,944,416.53$
2	0	577,826.56	-7,355,260.03	555,388.85	$-7,389,027.67$
3	0	577,826.56	-6,777,433.47	544,498.88	-6,844,528.80
4	0	577,826.56	-6,199,606.90	533,822.43	-6,310,706.37
5	0	577,826.56	-5,621,780.34	523,355.32	-5,787,351.05
6	0	577,826.56	-5,043,953.77	513,093.45	-5,274,257.59
7	0	577,826.56	-4,466,127.21	503,032.80	-4,771,224.80
8	0	577,826.56	-3,888,300.65	493,169.41	$-4,278,055.39$
9	0	577,826.56	-3,310,474.08	483,499.42	-3,794,555.97
10	0	577,826.56	-2,732,647.52	474,019.04	-3,320,536.93
11	0	577,826.56	-2,154,820.95	464,724.55	-2,855,812.38
12	0	577,826.56	-1,576,994.39	455,612.30	-2,400,200.08
13	0	577,826.56	-999,167.82	446,678.73	-1,953,521.35
14	0	577,826.56	-421,341.26	437,920.32	-1,515,601.03
15	0	577,826.56	156,485.30	429,333.65	-1,086,267.38
16	0	577,826.56	734,311.87	420,915.34	-665,352.04
17	0	577,826.56	1,312,138.43	412,662.10	$-252,689.94$
18	0	577,826.56	1,889,965.00	404,570.69	151,880.75
19	0	577,826.56	2,467,791.56	396,637.93	548,518.68
20	0	577,826.56	3,045,618.12	388,860.71	937,379.39
21	0	577,826.56	3,623,444.69	381,235.99	1,318,615.38
22	0	577,826.56	4,201,271.25	373,760.78	1,692,376.16
23	0	577,826.56	4,779,097.82	366,432.14	2,058,808.30
24	0	577,826.56	5,356,924.38	359,247.19	2,418,055.49
25	0	577,826.56	5,934,750.95	352,203.13	2,770,258.62

Figure 4 provides a graphical representation of the NPV trend over time, aligning with these financial assessments.

Table 6. Trend of the three economic indicators over the years

Indicator in Years	NPV	PI	IRR
10 Y	$-3,320,536.93$	-0.45	-8.32
15 Y	$-1,086,267.38$	-0.18	-1.74
20 Y	$937,379.39$	0.06	1.09
25 Y	$2,770,258.62$	0.28	2.51

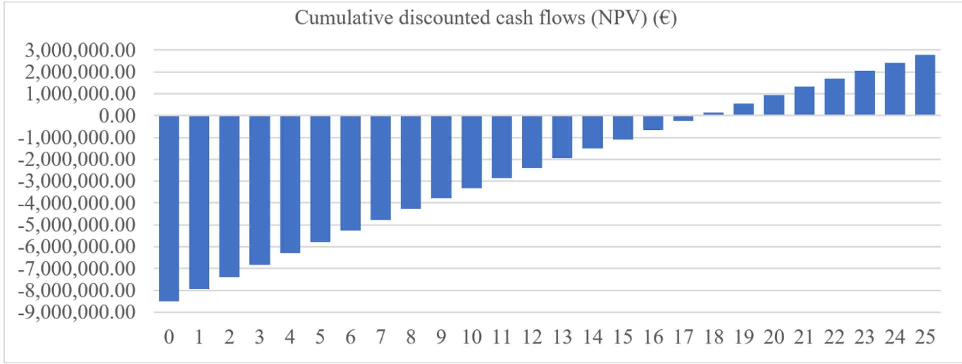

Figure 4. Trend of the NPV of the planned interventions over time (years)

In addition to these calculations, potential incentives and loans are evaluated to further optimize the financial framework, maximizing the economic benefits while minimizing upfront costs. This holistic approach ensures that the most financially sound interventions are prioritized, supporting sustainable energy improvements.

To conclude the economic framework, Table 6 shows not only the NPV trend but also the IRR and IP trend over the years, confirming that the payback period is around seventeen years.

6 Proposed 2020-2030 Action Plan

For the years considered, 2022-2024, UNIBAS's energy consumption has been relatively stable, with minor fluctuations due to climatic conditions and changes in occupation profiles. The implementation of the interventions discussed in the preceding paragraph can significantly reduce the UNIBAS electricity and gas consumption [32].

The plan is divided into two macro intervention categories:

a) General Energy Plan

Energy efficiency is the top priority of the energy strategy because it contributes simultaneously to achieving the objectives of cost, competitiveness, safety, economic growth, and environmental quality.

The purpose of the energy redevelopment proposal for the university campus is to implement a series of interventions aimed at both reducing energy needs (modernization and replacement of some equipment, and thus efficiency interventions) and generating energy through the use of renewables.

Using components and technologies of the most recent generation (LEDs, flow regulators, materials with particular thermal and acoustic insulation properties) is the strategy for energy efficiency interventions in order to guarantee substantial savings on current management costs. The combination of LED technology with a suitable control and communication system (such as DALI) can result in lighting-related energy savings of over 90% [33].

b) System for Control, Management, Monitoring, and Maintenance

The plant's control, management, and monitoring system enable the monitoring of all internal parameters of the conversion groups and all connected strings. It is accessible from any network-connected device (tablet, smartphone, laptop) and can generate alert messages whenever an anomaly occurs at a system node. Through a precise mapping of the system, any anomaly's root cause is immediately determined.

The attainable objectives for 2030 could include the following:

- a 20% reduction in electricity consumption, as a result of the new power plants, which will result in annual savings of approximately 250,000 euros. By estimating an annual consumption of approximately 2.2 million kWh, we assume an annual production of approximately 1.4 million kWh (approximately 65% of the total).
- a 15% reduction in gas consumption;
- a jump of at least two energy classes for buildings in the lowest energy class;
- a 15% increase in the proportion of self-produced energy from the Sources of Renewable Energy (RES).

This is a very important initiative, as it pursues the university's objective of growth in terms of environmental concerns and energy production: we aim to make the Macchia Romana structure almost completely self-sufficient, while simultaneously redeveloping spaces ranging from green and parking areas to buildings.

In the context of the Integrated National Energy and Climate Plan 2030 [34], which contributes to the European energy and environmental objectives, smart grids are essential to the management of progressive decarbonization.

Hence the significance of integrated local energy communities, which can be defined as a collection of energy consumers who agree to make shared decisions to meet their energy needs. The objective is to maximize the benefits derived from this collaborative approach by implementing multigenerational technological solutions for distributed energy generation and intelligent energy flow management.

The search for design and management solutions for an integrated local energy community is a complex, multi-stakeholder decision-making process characterized by the presence of frequently competing objectives.

The implementation of the action proposes a multi-objective approach to identify compromise solutions between the objectives of interest of the various stakeholders involved in the energy transition in various capacities and levels, ensuring the economic and environmental sustainability of the energy community.

Consider the Macchia Romana Campus; potential participants could include the Potenza Municipality, the San Carlo Hospital, and/or nearby schools, etc.

To conceive of the UNIBAS Energy Community, it is necessary to characterize the energy model, with reference to smart grids as described above, using technologies and tools that are already present in the existing regulatory framework, but which require support measures and regulatory framework.

A fundamental component for the implementation of the consumption rationalization action plan is the promotion of an awareness-raising campaign for energy-sustainable behavior. The first step in achieving every energy-saving objective is recognizing that everyone's contribution can make a difference, without disrupting established routines, by simply learning to use energy more efficiently.

In light of what has been stated thus far, it is necessary to develop a combination of comprehensive energy efficiency measures that can incorporate various functions.

Important aspects include the optimization of existing systems, plants, and components, as well as the application of new materials and generation systems that maximize production from renewable sources.

6.1 Feasibility Discussion

While the strategies outlined above propose various measures to enhance energy efficiency across the university's campus, they lack a detailed analysis of the feasibility and potential obstacles in their implementation. One significant challenge is the financial investment required for retrofitting existing systems and structures, such as upgrading the heating plant and integrating energy-efficient technologies like LED lighting and smart control systems. Although these improvements are projected to yield long-term savings, the initial capital expenditure could be a barrier, particularly in the context of limited public or institutional funding. Moreover, the integration of new technologies—such as intelligent lighting systems, smart thermostats, and energy management software—requires skilled labor for installation and ongoing maintenance. This raises concerns about the availability of trained personnel and potential operational disruptions during the transition period.

Another crucial challenge lies in the compatibility of existing infrastructure with new systems. For example, incorporating renewable energy sources such as photovoltaics, though environmentally beneficial, may require substantial adjustments to the grid and backup systems, as well as load management capabilities. This can be particularly problematic in older buildings that were not designed for modern energy systems. Additionally, resistance from building occupants and staff may arise when new systems are introduced, particularly if they affect comfort levels or operational routines. For instance, reducing heating hours or limiting the use of elevators could face pushback from users unless accompanied by educational campaigns or incentives.

Risk factors also include unforeseen technical issues, such as system failures or lower-than-expected energy savings due to suboptimal usage patterns or misaligned control systems. To mitigate these risks, a robust plan for monitoring and adapting systems based on real-time data is essential, along with regular training and engagement programs for staff and students to promote efficient energy use. The complexity of implementing these strategies emphasizes the need for a phased approach, where pilot projects can be tested and optimized before full-scale rollout, allowing for lessons learned to inform broader application. Ultimately, while the proposed measures show significant potential, a comprehensive risk assessment and cost-benefit analysis made in the previous paragraph are crucial to ensuring their successful implementation and long-term sustainability.

7 Comparative Analysis of Energy Audit Case Studies in Literature

To compare the case studies aforementioned with the study conducted at UNIBAS, both qualitative and analytical aspects are addressed, based on key dimensions:

1. Methodology and Approach

- UNIBAS: The study focuses on an energy audit conducted in alignment with the ISO 50001 framework, incorporating both technical and managerial strategies. It includes the use of dynamic simulation to optimize energy-saving measures and predictive modeling to account for seasonal variations in energy consumption.
- Other Studies:
  (French University): This study integrates thermal comfort and indoor air quality into the energy audit, providing a transversal view of operational conditions. It emphasizes the role of occupant behavior in energy consumption, similar to the UNIBAS study [22].
  (Jordan): Here, a low-cost methodology is applied using available data for auditing, avoiding the need for complex simulations, which contrasts with the more detailed simulations used at UNIBAS [24].

(Italy): The energy audit aimed to transform a school into a nearly zero-energy building, considering external heat inputs. This case goes beyond UNIBAS by integrating zero-energy building concepts [27].
(Ukraine): This study applies multivariate and cluster analysis to identify energy-saving measures, focusing on resource management. While UNIBAS also includes management strategies, it doesn't emphasize these specific analytical tools [29].

2. Scope and Focus

- UNIBAS: The project includes a comprehensive campus-wide energy audit covering different building types (classrooms, laboratories, administrative offices) and utilizing a phased approach to energy efficiency improvements. The interventions are divided into short-term (e.g., communication, lighting upgrades) and long-term (e.g., HVAC system renovations) strategies .
- Other Studies:
  Focuses primarily on occupant behavior and thermal comfort in the audit, which is less technically intensive than UNIBAS's dynamic simulations [22].
  (India): The goal was more focused on raising community awareness about energy consumption, contrasting with the more technical and policy-driven goals of the UNIBAS project [26].
  (LEED Integration in the U.S.): Focuses on integrating sustainability protocols such as LEED, which provides a certification goal absent from the UNIBAS study, where the focus is more on technical energy performance and policy compliance [30].

3. Quantitative Results

- UNIBAS: The energy audit identified potential CO_2 savings, aiming for a 25% reduction in electricity demand and a 15% reduction in gas consumption. The projected payback period for the investment is around 17 years.
- Other Studies:
  (Bologna): Identified potential savings of 32% by improving heating systems, which is comparable to the UNIBAS case in terms of overall savings [25].
  Focused more on qualitative issues such as irrational energy use and resource management, lacking the detailed quantitative assessments like the NPV analysis conducted in UNIBAS [29].
  (Turin): Aimed to reduce energy consumption by converting the school into a nearly zero-energy building, which represents a more ambitious target than the gradual reductions planned in the UNIBAS study [27].

4. Technological Innovations

- UNIBAS: The integration of smart grids, automation, and real-time energy monitoring is emphasized, with renewable energy sources (photovoltaic panels and trigeneration plants) providing self-generated electricity for the campus. These technological solutions align with European regulations on building energy performance.
- Other Studies:
  Integration with LEED protocols introduces a sustainability framework for energy auditing, but lacks the dynamic simulation and smart grid integration seen at UNIBAS [30].
  Focuses on low-tech, low-cost solutions, avoiding expensive or cutting-edge technology like smart grids or dynamic simulation, marking a divergence in approach compared to UNIBAS [24].

5. Policy and Sustainability Integration

- UNIBAS: The study aligns with European and Italian regulations, incorporating the Energy Roadmap 2050 and integrating national energy and climate plans. The project aims to align with future sustainability goals through renewable energy integration and long-term carbon reduction goals.
- Other Studies:
  In the U.S., LEED certification sets a sustainability benchmark, ensuring that the energy audit is tied to specific environmental performance goals, which is a different but complementary policy framework compared to UNIBAS's adherence to European standards [30].
  The nearly zero-energy building concept in Turin aligns with European directives on energy performance, making it a more ambitious policy alignment compared to UNIBAS's gradual approach [27].

The study conducted at UNIBAS offers a comprehensive, technology-integrated approach with a clear alignment to European policies, using dynamic simulations and smart grid technologies for long-term energy management. Comparatively, some of the other case studies (e.g., [24, 26]) emphasize low-cost, practical solutions with limited technological complexity, while others (e.g., [27, 30]) introduce advanced sustainability goals like LEED certification or nearly zero-energy buildings. Overall, the UNIBAS study stands out for its technical depth and policy-driven strategies, although it can benefit from integrating some of the sustainability frameworks seen in other studies.

8 Conclusions

Modelling a "standard building" with reliability, flexibility, and general validity remains a significant challenge due to the distinct characteristics of each structure, compounded by the scarcity of detailed research on the energy performance of university buildings. The complex organizational structure of UNIBAS, with its multiple research centers, departments, and faculties, further complicates categorization and benchmarking. However, this study addresses these challenges head-on, offering critical insights into energy efficiency measures that can be scaled and adapted across different academic institutions.

The scientific significance of this research lies in its innovative approach to conducting energy audits in educational settings. By integrating dynamic simulation, predictive modelling, and EnPIs, the study offers a robust framework for assessing energy use and identifying potential savings. The use of dynamic modelling in particular allows for a more precise understanding of seasonal variations in energy demand and the impact of external conditions on building performance. These methodologies are aligned with best practices outlined in ISO 50001, providing a rigorous, data-driven basis for decision-making. The findings contribute to the growing body of literature that emphasizes the need for both technical optimization and behavioral interventions to bridge the gap between theoretical and actual energy performance. This study's integration of advanced auditing tools and real-time data systems enhances its relevance and utility for both academic researchers and practitioners in the field of energy management.

From a practical perspective, this research has far-reaching implications for universities and other large public institutions seeking to reduce their environmental footprint while managing operational costs. The proposed short-term interventions, such as the reduction of electricity and heat consumption through the implementation of designed measures, address immediate energy inefficiencies. These measures, which include communication campaigns and behavior-based strategies, are cost-effective and quickly deployable, providing a tangible starting point for energy savings.

The long-term interventions recommended in the study are equally significant. These include a comprehensive transition to renewable energy sources, improved lighting systems (relamping), and the implementation of a building automation control (BAC) system to optimize mechanical system operations. The projected 25% reduction in electricity consumption and 15% decrease in gas usage are substantial and demonstrate the potential for significant operational cost savings and environmental benefits. Furthermore, the study highlights a 17-year payback period, which, while moderate, confirms the financial viability of the proposed interventions. These results establish a clear pathway for institutions to achieve compliance with the Energy Roadmap 2050 and European Green Deal targets for decarbonization and energy efficiency.

The formation of a dedicated energy management unit is another practical outcome with profound implications for institutional energy strategies. This unit will oversee the implementation and monitoring of energy-saving measures, ensuring that the campus's energy performance is continuously optimized. By focusing on real-time data monitoring, the Energy Management unit can adapt strategies dynamically, responding to changes in building usage, climate conditions, and technological advancements. The interdisciplinary structure of the unit, organized around specialized work groups, ensures that the evolving demands of energy efficiency are met with flexibility and expertise.

The UNIBAS Action Plan for Energy Sustainability (2022-2050) is designed to be adaptable and expandable. While it represents a significant step forward, the study emphasizes that continued investment in energy-saving measures will be necessary to achieve the university's long-term goals. Ministerial, European, regional, and private funding will play a crucial role in scaling the plan's interventions. Future research and additional funding will enable a more comprehensive energy diagnosis, incorporating multi-seasonal data, occupancy rate studies, and external environmental factors. On the economic feasibility aspect, by incorporating advanced statistical and modeling methods into the analysis, the interventions' expected benefits and validity of conclusions will be more robustly supported, leading to more informed decision-making and optimization of energy efficiency strategies. Comprehensively, this would allow for a more precise and dynamic analysis of the campus's energy behavior, further refining the pathway toward nearly zero-energy buildings.

Looking ahead, the study opens new avenues for research. One area of exploration is the integration of a sensor-based monitoring network to gather real-time energy data. This would enhance the predictive accuracy of energy models and allow for the development of AI-driven energy management systems. Another promising direction is the examination of how occupant engagement and behavioral modifications can contribute to more sustainable energy use in university buildings. Moreover, future studies should explore the potential for energy storage solutions and the role of microgrids in enhancing energy resilience and sustainability.

In conclusion, this study presents a scientifically rigorous and practically relevant roadmap for improving energy efficiency in educational institutions. It contributes significantly to the literature on energy management by demonstrating how advanced auditing tools and strategic planning can result in substantial energy and cost savings. The phased approach outlined in this research ensures that both immediate energy savings and long-term sustainability goals can be achieved, making it a compelling model for universities and public institutions seeking to reduce their carbon footprint and operational costs. The next phase will focus on expanding these measures, incorporating dynamic energy analysis and advanced technologies to further enhance the campus's energy efficiency.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no competing interests.

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Nomenclature

$DALY$	Disability-Adjusted Life Years, dimensionless
EER	Energy Efficiency Ratio, dimensionless
$EnPI$	Energy Performance Indicator, dimensionless
IRR	Internal Rate of Return, dimensionless
NPV	Net Present Value, dimensionless
PI	Profitability Index, dimensionless
U	Transmittance, $\mathrm{W} \cdot \mathrm{m}^{-2} \cdot \ \mathrm{K}^{-1}$

Acronymous

CAM	Minimum Environmental Criteria
EPS	Sheets of Expanded Polystyrene
FL	Fluorescent
IAQ	Indoor Air Quality
LCA	Life Cycle Assessment
RES	Sources of Renewable Energy