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Master of Science Thesis

Enhancing Energy Efficiency in Italian School Buildings: A Comparative Study of Sustainable Strategies with use of BIM and Edilclima

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Abstract

This thesis has been created thanks to a collaboration with Città Metropolitana di Torino under the European Urban Initiative, planning innovative projects in sustainable urban development. This collaboration aims to show the project's alignment with broader European initiatives for promoting smart, sustainable urban environments.

This study seeks to investigate the potential for improving energy efficiency through the integration of sustainable practices and the consideration of economic factors. By examining the alliance between sustainable development goals and cost-effective energy management strategies, this research aims to identify opportunities for enhancing energy efficiency within a framework that promotes both environmental stewardship and financial stability.

A significant aspect of strategies to improve energy efficiency in Italian school buildings, concentrating on the Amaldi Sraffa high school complex in Orbassano, Italy, as a case study. By integrating conceptualization and implementation strategies, the research highlights the significance of Building Information Modeling (BIM) and energy efficiency software, Edilclima, in simulating and assessing enhancements while ensuring alignment with European Technical Standards.

The study seeks to enhance energy efficiency through a case study analysis, the research examines the sustainability and economic feasibility of implementing energy-efficient strategies in the school complex. By conducting a SWOT analysis and assessing the climate, energy usage, and architecture of the area, the study aims to identify potential strategies for improvement. Utilizing Building Information Modeling (BIM) and energy efficiency software Edilclima, the research proposes design hypotheses to create a more sustainable and economically viable educational facility. This approach acquires knowledge from past retrofitting projects and considers the evolution of schools in Italy to develop effective strategies for enhancing energy efficiency in the Amaldi School complex, ultimately contributing to a more sustainable built environment.

The thesis focuses on comparing various hypotheses aimed at enhancing energy efficiency and insulation solutions for existing school buildings in Italy. These hypotheses include the integration of renewable energy source solar panels, and the replacement of current systems with high-efficiency models. Additionally, the research investigates insulation solutions by comparing three approaches: the integration of green roofs, insulation with EPS (Expanded Polystyrene), and insulation with WFP (Wood Fiber Panels), considering both sustainability and economic evaluations. The role of Building Information Modeling (BIM) and the Edilclima application is emphasized in simulating and analyzing these improvements, showcasing their potential to significantly enhance the energy performance of the school complex. To evaluate these enhancements, solutions will be assessed using green building rating systems based on results from the Edilclima software, ensuring compliance with European Technical Standards.

The findings aim to provide a valuable reference for future projects, encouraging the adoption of technologies that promote cost-effective and sustainable practices in retrofitting educational facilities. This research addresses current energy challenges while laying the groundwork for more resource-efficient learning environments for future generations.

Key Words: BIM as-built model, energy efficiency in Italian school buildings, Edilclima, enhancing existing schools

Abstract

Questa tesi è stata creata grazie alla collaborazione con Città Metropolitana di Torino nell'ambito European Urban Initiative, pianificando progetti innovativi nello sviluppo urbano sostenibile. Questa collaborazione mira a mostrare l'allineamento del progetto con le più ampie iniziative europee per la promozione di ambienti urbani intelligenti e sostenibili.

Questo studio cerca di indagare il potenziale per migliorare l'efficienza energetica attraverso l'integrazione di pratiche sostenibili e la considerazione di fattori economici. Esaminando l'alleanza tra obiettivi di sviluppo sostenibile e strategie di gestione energetica economicamente vantaggiose, questa ricerca mira a identificare opportunità per migliorare l'efficienza energetica all'interno di un quadro che promuove sia la tutela ambientale che la stabilità finanziaria.

Un aspetto significativo delle strategie per migliorare l'efficienza energetica negli edifici scolastici italiani, concentrandosi sul complesso scolastico superiore Amaldi Sraffa a Orbassano, in Italia, come caso di studio. Integrando strategie di concettualizzazione e implementazione, la ricerca evidenzia l'importanza del Building Information Modeling (BIM) e del software di efficienza energetica, Edilclima, nella simulazione e valutazione dei miglioramenti, garantendo al contempo l'allineamento con gli standard tecnici europei.

Lo studio cerca di migliorare l'efficienza energetica attraverso un'analisi di casi di studio, la ricerca esamina la sostenibilità e la fattibilità economica dell'implementazione di strategie di efficienza energetica nel complesso scolastico. Conducendo un'analisi SWOT e valutando il clima, l'uso di energia e l'architettura dell'area, lo studio mira a identificare potenziali strategie di miglioramento. Utilizzando il Building Information Modeling (BIM) e il software di efficienza energetica Edilclima, la ricerca propone ipotesi di progettazione per creare una struttura educativa più sostenibile ed economicamente fattibile. Questo approccio acquisisce conoscenze da precedenti progetti di ristrutturazione e considera l'evoluzione delle scuole in Italia per sviluppare strategie efficaci per migliorare l'efficienza energetica nel complesso scolastico Amaldi, contribuendo in definitiva a un ambiente costruito più sostenibile.

La tesi si concentra sul confronto di varie ipotesi volte a migliorare l'efficienza energetica e le soluzioni di isolamento per gli edifici scolastici esistenti in Italia. Queste ipotesi includono l'integrazione di pannelli solari da fonti di energia rinnovabile e la sostituzione degli attuali sistemi con modelli ad alta efficienza. Inoltre, la ricerca esamina le soluzioni di isolamento confrontando tre approcci: l'integrazione di tetti verdi, l'isolamento con EPS (polistirene espanso) e l'isolamento con WFP (pannelli in fibra di legno), considerando sia la sostenibilità che le valutazioni economiche. Il ruolo del Building Information Modeling (BIM) e dell'applicazione Edilclima è enfatizzato nella simulazione e nell'analisi di questi miglioramenti, mostrando il loro potenziale per migliorare significativamente le prestazioni energetiche del complesso scolastico. Per valutare questi miglioramenti, le soluzioni saranno valutate utilizzando sistemi di classificazione degli edifici verdi basati sui risultati del software Edilclima, garantendo la conformità con gli standard tecnici europei.

I risultati mirano a fornire un prezioso riferimento per progetti futuri, incoraggiando l'adozione di tecnologie che promuovano pratiche sostenibili ed economiche nella ristrutturazione di strutture educative. Questa ricerca affronta le attuali sfide energetiche gettando le basi per ambienti di apprendimento più efficienti in termini di risorse per le generazioni future.

Parole chiave: modello BIM as-built, efficienza energetica negli edifici scolastici italiani, Edilclima, valorizzazione scuole esistenti

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SD	Sustainable Development
CAM	The Minimum Environmental Criteria (I Criteri Ambientali Minimi)
ARCA	Architecture Comfort Environment (Architettura Comfort Ambiente)
BREEAM	Building Research Establishment Environmental Assessment Method
LEED	Leadership in Energy and Environmental Design
nZEB	Nearly Zero-Energy Building
IEA	International Energy Agency
IPCC	The Intergovernmental Panel on Climate Change
UN	United Nations
WMO	World Meteorological Organization
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificates
APE	Energy Performance Certificate (Attestato Di Prestazione Energetica)
DM	Ministerial Decree for Energy Efficiency Requirements in Buildings
BIM	Building Information Modeling
AEC	Architecture, Engineering, And Construction
CAD	Computer-Aided Design
LOD	Level of Detail
IFC	Industry Foundation Classes
Epgl,Nren	Non-Renewable Energy Performance Index
DHW	Domestic Hot Water
PV	Photovoltaic Panels
EGR	Extensive Green Roof
IGR	Intensive Green Roof
EPS	Expanded Polystyrene
WFP	Wood Fiber Panels

1. INTRODUCTION

Schools are more than just places that provide cognitive, academic, and professional skills but places that raise children to become individuals who participate in society, enable them to socialize with their peers and adults, and shape their emotional development. (Crosnoe, 2015). According to the data at Eurydice (Italy, n.d.), education in Italy starts at the age of 6 and is mandatory to receive education for 10 years. With the motto 'Everyone has a right and a duty to receive education'. Schools are places where people spend years, and it is possible to see how important they are in shaping society. The architecture of these institutional buildings has also been shaped in time to be suitable for formation and pedagogy.

The history of schools in Italy has evolved significantly since the 18th century. Initially, education was primarily private, but from the mid-1700s, there was a shift towards public schooling, particularly in Lombardy (Dal Passo, 2003). The 19th century saw the development of rural and multi-grade schools, challenging the notion that compulsory education began with Italy's unification (Pruneri, 2018). In the early 2000s, research focused on the material history of schooling, examining the production and adoption of textbooks, exercise books, and school furnishings, which contributed to the standardization of teaching methods. This diverse history reflects Italy's ongoing efforts to establish and improve its educational system over the centuries (Meda & Polenghi, 2021).

Research on school design emphasizes the interconnection between physical spaces and educational practices. School architecture reflects and influences pedagogical approaches, cultural values, and societal expectations about teaching and learning (Darian-Smith & Willis, 2017). Child development is a central consideration in elementary school design, with emphasis on varied scales, nature exposure, and interactive spaces (Rigolon & Alloway, 2011). Studies have identified direct impacts of physical factors on academic achievement, such as school and classroom size, as well as effects on non-academic behaviors related to location and study spaces (Moore & Lackney, 1993). The challenge lies in bridging the gap between educators and designers to create environments that support evolving pedagogical practices and technological advancements (Darian-Smith & Willis, 2017; Rigolon & Alloway, 2011).

As of the latest update (30/04/2024) from the (Anagrafe dell'Edilizia Scolastica, 2024), there are approximately 41,000 schools in Italy. This number includes all types of educational institutions, such as primary, secondary, and higher education facilities. (Anagrafe dell'Edilizia Scolastica, 2024) as cited in (Guarini, Morano, & Sica, 2020) shows 22,000 of which school buildings were constructed before 1970. Over half of these buildings (57.5%) have measures to reduce energy consumption, and 53.2% possess a static test certificate. Of the buildings lacking this certificate, 22.3% were built before 1970. Additionally, 59.5% of the buildings do not have a fire prevention certificate, and 53.8% lack a habitability certificate. On a more positive note, 78.6% of schools have an emergency plan, and 74.5% have had architectural barriers removed. (Anagrafe dell'Edilizia Scolastica, 2024) as cited in (Guarini, Morano, & Sica, 2020). Even though there are regional disparities between North and South many schools all around the country lack infrastructure quality, safety certifications, energy efficiency, and availability of services (Laurenti & Trentin, 2023).

To take a closer look at energy efficiency at schools it is necessary to address the definition of energy classes. Energy classes are introduced in EU Directive 92/75/EC (1992) to give an idea for the energy amount that consumed. It is determined with color associated with letters from A to G, A meaning the more efficient and G is the least. It is possible to say that schools in Italy are mainly in lower energy classes. 74.8% of schools are in the lowest three energy classes (E, F, G) with only 4.2% of schools in the highest energy efficiency class A. With numbers showing that efficiency is low, some schools have benefitted from energy efficiency improvements in the last five years. 17.1% of school buildings have undergone energy efficiency improvements. Some of these interventions were the replacement of boilers, windows, and doors, insulation of roofs and external walls, etc. (Laurenti & Trentin, 2023).

It is also possible to mention various problems that school buildings have. Indoor environmental risk is one of the risks that occurs at school buildings. According to the information from (Laurenti & Trentin, 2023) shows that only %48.1 of the buildings tested for asbestos. %5.6 of the school buildings that tested in Italy contain asbestos. Asbestos are mineral fibers that are known to fibers are known to cause serious health problems (British Lung Foundation, 2021).Another indoor environmental risk is Radon Gas (Laurenti & Trentin, 2023), which is a gas that can cause lung cancer according to the Environmental Protection Agency. (Health Risk of Radon, 2024). Radon gas exposure can happen in indoor places with low amounts of air exchange. Air leaks from the soil which causes an exposed foundation to the indoor spaces and basements creates hazard. (Cooney, 2010). Only 56.3% of schools have been monitored for radon gas, and 1% of schools have radon levels above legal limits (Laurenti & Trentin, 2023).

In Italy, schools constitute a significant portion of public property. As of 2024, many educational buildings require redevelopment, addressing both structural and mechanical aspects as well as the management of teaching and social spaces. Despite various legislative efforts to standardize school construction practices, there is no comprehensive regulatory framework that integrates both technical and functional management aspects of school facilities (Guarini, Morano, & Sica, 2020).

All the points mentioned above reveal that most of Italy's school buildings are older and were built according to outdated technological and educational standards. Only those built after 1975 adhere to the modern typological specialization required by current legislation, which aligns with new international educational guidelines. According to these guidelines, schools are no longer viewed merely as spaces for educational activities but also as places that contribute to the livability of their surrounding urban environments. (Anagrafe dell'Edilizia Scolastica, 2024) as cited in (Guarini, Morano, & Sica, 2020).

Given that a significant number of school buildings in Italy are characterized by outdated technology and educational standards, the consideration of retrofitting these structures comes to mind as a solution. Retrofitting involves the modernization of existing buildings to meet current technological and educational requirements and aims to result in enhancing their functionality and efficiency. This process is particularly crucial for addressing the differences between older buildings and current standards and regulations, ensuring that educational environments are benefitting from current pedagogical practices and safety regulations (Chrysostomou et al, 2013).

The importance of this thesis lies in its potential to address critical challenges faced by many educational institutions in Italy, particularly those related to outdated infrastructure and energy inefficiency. By focusing on the retrofitting of the Amaldi School complex in Orbassano, the research highlights the urgent need for modernization in school buildings, which are essential environments for learning and development.

This study aims to contribute to the broader discourse on sustainable architecture by exploring innovative strategies that enhance energy efficiency while also considering economic viability. By integrating advanced technologies such as Building Information Modeling (BIM) and energy efficiency software, the thesis aims to showcase how data-driven approaches can lead to effective retrofitting solutions that comply with European Technical Standards. Moreover, the findings of this research are not only relevant for the Amaldi School complex but also serve as a valuable reference for similar projects aimed at improving educational facilities across Italy.

The study begins with a reviewing state of art, which lays the foundation for understanding the core concepts, standards, and regulations related to sustainability, energy efficiency, and Building Information Modeling (BIM) in the context of building design and retrofitting. The review is structured into three main sections: sustainability, energy efficiency, and BIM, each addressing crucial aspects relevant to sustainable building practices and retrofitting strategies.

The sustainability part explores the various definitions and general concepts of sustainability, emphasizing its importance in building design. Also, with focusing on sustainable building certifications provide frameworks for evaluating and improving a building's environmental performance. Lastly, this section examines three school buildings in Italy that have undergone similar retrofitting projects, evaluating their sustainability outcomes and economic performance.

The energy efficiency section begins with general definitions, then focuses on the building scale and examines today's energy efficiency rules and regulations from general to specific, from worldwide to European and most recently Italian standards.

Following the general definitions of BIM, the review delves into more specific concepts, such as BIM dimensions and Level of Detail (LOD). It also explores key areas like As-Built Modeling, Point Cloud integration, and the interoperability of BIM with IFC.

After the state-of-the-art section, the methodology of the thesis is outlined. This section explains the key research questions the thesis aims to address, the approaches it will adopt, and the rationale behind selecting these approaches.

In the following section, the Amaldi Sraffa Complex will be analyzed in detail as a case study. The territorial and urban planning framework explores the relationship between the school and its surrounding environment, while the climatic framework provides an in-depth examination of Orbassano's climate, where the school is located. The next section focuses on the energy assessment of the buildings, using existing data and analyses previously gathered. This information is then synthesized into a SWOT analysis, followed by an evaluation of the findings.

After the analysis, the complex will be modeled as built using BIM, which is essential for developing design hypotheses. The building will be modeled with the highest possible level of detail, utilizing systems like point cloud, and key details such as the level of detail (LOD) will also be outlined in this section. Finally, the integration of the model with Edilclima for energy performance simulations will be explored.

As for the design hypotheses, they are divided into two main parts: the first is hypotheses regarding energy efficiency and the second is regarding insulation. Two different approaches will be proposed to reduce energy consumption for the Amaldi Sraffa high school building. The first hypothesis suggests integrating solar panels into the existing building to harness renewable energy. The second hypothesis focuses on replacing the current condensing boilers with high-efficiency models to improve heating performance. For the approaches regarding insulation, three approaches for enhancing roof insulation are going to be explored. The first approach aims to optimize a green roof, the second involves insulating the roof with expanded polystyrene (EPS), and the third considers using wood fiber panels as an alternative insulation material. Once all approaches are examined, they will be evaluated from both an economic and sustainability perspective.

In the recommendations section, based on the evaluation results, a combined solution that integrates energy efficiency and insulation strategies will be proposed for the Amaldi Sraffa case study to achieve the optimal outcomes.

Finally, the conclusion will assess whether the thesis has achieved its objectives and addressed the research questions, evaluating whether the results met the initial expectations. It will also emphasize the role of BIM and the Edilclima energy simulation in guiding effective sustainable retrofitting decisions.

1.1 Subject

In Italy, many school buildings are equipped with outdated technologies and do not meet contemporary educational standards, making retrofitting a viable solution. Retrofitting entails upgrading existing structures to align with modern technological advancements and educational needs, thereby improving their overall functionality and efficiency. This thesis focuses on a detailed case study of the Amaldi School complex in Orbassano, with a specific emphasis on enhancing energy efficiency. By examining this case, the research aims to evaluate retrofitting strategies from both sustainability and economic perspectives, ensuring that the upgrades not only reduce energy consumption and environmental impact but also provide financial benefits. Ultimately, the goal is to demonstrate how retrofitting can transform educational facilities into more effective and sustainable environments.

1.2 Purpose

The purpose of this thesis is to investigate and evaluate various strategies aimed at improving energy efficiency in Italian school buildings, specifically focusing on the Amaldi Sraffa high school complex in Orbassano. This includes examining the integration of renewable energy sources, such as solar panels, and the replacement of existing heating systems with high-efficiency models. Additionally, the study aims to analyze insulation solutions, including green roofs and different insulation materials, while leveraging BIM and Edilclima software to simulate and assess these enhancements.

2. STATE OF ART

2.1 Sustainability

To explain sustainability by looking at the dictionary definition, 'relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged.' (Sustainability, n.d.) would be only scratching the surface.

The concept of sustainability as comprising three pillars - social, economic, and environmental - has become widely accepted, but its origins and theoretical foundations are not clearly defined (Purvis, 2018).This three-pillar model emerged gradually from critiques of economic priorities in early academic literature and United Nations efforts to reconcile economic growth with social and ecological concerns. The three-pillar model of sustainability, represented by three intersecting circles, is widely used but has no single clear origin, instead emerging gradually from various academic and policy perspectives (Purvis, 2018). The framework is applied in various contexts, including building sustainability (Eklová, 2020) and local government initiatives (Opp & Saunders, 2013). It serves as a strategic approach for developing solutions that simultaneously address all three pillars through technology and innovation, laws and governance, and economics and financial incentives (Clune & Zehnder, 2018).

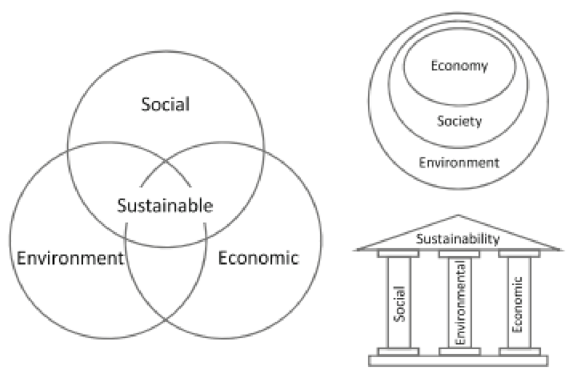


Figure 1 Common diagrams representing concept of sustainability (Purvis, 2018)

As seen in Figure 1, There are different ways of representing the concept of sustainability. The first one on the left is the popular three-circle diagram representing this concept was first presented by Barbier in 1987. As well as on the right two other representations can be seen. One on the bottom is 3 pillars that carries the sustainability, referencing more of a literal representation, whilst the other one on top is three intersecting circles (Purvis, 2018).

While the Brundtland Report of 1987 providing a famous definition "Our Common Future," introduced the concept of sustainable development, defining it as "development that meets the needs of the present without compromising the opportunities of future generations to meet their own needs" (CHIRITESCU, 2013). The concept of sustainability has a rich history dating back centuries, with roots traceable to the 1660s (Caradonna, 2017). The idea of "sustainable yield" gained traction in Europe in the 1660s, leading to the early development of sustainable forestry methods and highlighting the need of striking a balance between resource extraction and natural regeneration. The tremendous economic growth and environmental deterioration of the Industrial Revolution led experts to reevaluate how humans interact with the natural world, further building the foundation for the sustainability movement (Caradonna, 2017). The historiography of sustainability has emerged as a subfield, with two main branches: one focusing on intellectual and cultural origins, and another examining the unsustainability of past collapsed societies (Caradonna, 2017). The evolution of sustainability encompasses various fields, including sustainable yield forestry, environmental conservation, and ecological economics (Caradonna, 2017). Understanding the historical, political, and social processes that led to the emergence of global environmental consciousness is crucial for researchers in the field (Lira & Fraxe, 2014).

This history includes significant intergovernmental conferences since the 1970s, such as the Stockholm Conference and Rio-92, which have shaped our current understanding of sustainability as a balance between planetary needs and human civilization (Lira & Fraxe, 2014).

Searching through the history of sustainable development, the most widely cited definition comes from the Brundtland Commission's 1987 report, describing it as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Emas, 2015). The concept encompasses three key pillars: economic, environmental, and social sustainability (Sinha Babu & Datta, 2016). It promotes the principles of reusing, recycling, and renewing resources to maintain ecological balance (Sinha Babu & Datta, 2016). Sustainable development seeks to integrate environmental policies with development strategies, ensuring the long-term preservation of natural capital and ecosystems for future generations (Sinha Babu & Datta, 2016).

Although there are also other thoughts for different approaches to sustainable development. Such as Boron and Kosiek (2019) highlight that while the popular "three-pillar" model of sustainable development is widely used, it may benefit from clearer definitions and a more structured system framework to improve its effectiveness. At its core, sustainability is about ensuring continuance, and sustainable development (SD) refers to a development path that can be sustained indefinitely. Common representations of SD, like the three-pillar "Venn diagram" model, may not fully capture the original, holistic vision outlined in the Brundtland report. These models, while helpful, might simplify or present sustainability as a balance of trade-offs, rather than an integrated, long-term approach that harmonizes environmental, societal, and economic needs.

Another historical event that shaped sustainability term is The United Nations Conference on the Human Environment in Stockholm, 1972, marked the beginning of a series of high-level global conferences addressing complex international issues (Biswas & Tortajada, 2023). This event-initiated discussions on sustainable development, which centers around intergenerational equity and three interconnected pillars: environment, economy, and society (Mensah & Ricart Casadevall, 2019). Subsequent conferences, including those on population, food, and water, aimed to raise awareness and develop strategies for global challenges (Biswas & Tortajada, 2023). These gatherings have been influential in shaping a global perspective on environmental issues and inspiring numerous initiatives at various levels. Despite conservation efforts, human actions continue to drive declines in nature, threatening biodiversity and ecosystem integrity (Díaz et al, 2019)Addressing these challenges requires transformative action from key players, including governments, the private sector, and civil society organizations, to promote sustainable development awareness and compliance (Mensah & Ricart Casadevall, 2019).

The Rio Earth Summit in 1992 marked a significant milestone in global efforts to address sustainable development and climate change (Wible, 2012). However, in the three decades since, progress has been inadequate. Despite numerous international conferences and agreements, greenhouse gas concentrations have continued to rise, exacerbating climate change impacts and slow onset events such as rising temperatures, sea levels, and biodiversity loss (Stavi, 2022). Media coverage of the Rio conferences in 1992 and 2012 reflects this shift, with a change from future-oriented hope to past-oriented disappointment regarding the implementation of climate change policies (Hellsten, Porter, & Nerlich, 2014). To achieve the goal of limiting global warming to 1.5°C or 2.0°C above preindustrial levels, more decisive and proactive policymaking is needed, along with substantial efforts in climate change mitigation, adaptation, and environmental conservation (Stavi, 2022).

2.1.1 Sustainability in Buildings

The built environment accounts for a substantial portion of final energy use (62%) and is a major contributor to greenhouse gas emissions (55%). To meet environmental objectives, including mitigating climate change, it is essential to employ thorough methodologies for accurately evaluating the impacts of this sector. Therefore, it is important to address sustainability in buildings. (Anderson et al., 2015). Sustainable building production principles have evolved over the past three decades, integrating various aspects of construction management. Integrated Planning for Sustainable Building Production incorporates leadership, health and safety, quality management, and environmental considerations (Mikaelsson & Larsson, 2017).

When it comes to sustainability in building construction encompasses environmental, economic, social, and technical aspects aimed at reducing negative impacts while enhancing quality of life (Zabihi & Habib, 2012). Key factors include energy efficiency, resource conservation, cost-effectiveness, and human adaptation (Akadiri Et Al, 2012). The concept extends beyond energy use to include carbon footprint, materials, recycling, urban planning, and water conservation (Stecky, 2020)

2.1.2 Sustainable Building Certifications

This section overviews the sustainability protocols mentioned at The CAM (I CRITERI AMBIENTALI MINIMI., 2022), which are used for assessing and certifying environmentally friendly building practices.

Architettura Comfort Ambiente (ARCA): A certification system aimed at ensuring comfort and environmental quality in buildings. It focuses on energy efficiency, indoor air quality, and the use of sustainable materials. (ARCA Certificazione, n.d.)

BREEAM (Building Research Establishment Environmental Assessment Method): Is one of the most widely recognized sustainability assessment methods in the world. It evaluates the environmental performance of buildings based on categories such as energy, health, and well-being, pollution, and innovation. (Sustainable Building Certification, n.d.)

LEED (Leadership in Energy & Environmental Design): A globally recognized certification program developed by the U.S. Green Building Council. It focuses on energy efficiency, water usage, materials selection, and indoor environmental quality. (LEED Certification for Existing Buildings and Spaces, n.d.)

WELL® Building Standard: This standard focuses on the health and well-being of building occupants. It addresses aspects such as air quality, lighting, fitness, and mental well-being to create healthier living environments. (WELL Standard, n.d.)

2.1.3 Sustainable Approaches for Educational Buildings in Italy

Considering the extensive need for retrofitting in many Italian school buildings, it is related to examine practical examples of such interventions. This chapter will present three case studies of school buildings from the 1970s that have undergone retrofitting processes. These case studies will illustrate the applied methodologies, how the specific approaches implemented, and the resulting impacts on functionality, energy efficiency, and compliance with contemporary educational standards. By analyzing these examples, it is aimed to provide insights into effective retrofitting strategies and their outcomes.

- **Tito Maccio Plauto school , Cesena , Italy**

The Tito Maccio Plauto secondary school in Cesena, a municipality of 100,000 people in the Emilia Romagna region of northeastern Italy, serves as the case study for the School of the Future Project. Based on base 20°C, the city falls under Class E of the national building climatic zoning, which is common for the country's northern regions. (Zinzi et al., 2014)
The building is part of a complex of sizable school and university buildings and is situated in the northeastern section of the city with regard to the city center. Despite the dense population in this location, there is enough space between buildings to allow for year-round exposure of the building facades to solar radiation. The structure was constructed in the 1960's, when no national or local codes for energy conservation in buildings were in force. (Zinzi et al., 2014)

Figure 2 Entrance of the Tito Maccio Plauto secondary school (Zinzi et al., 2014)

The total gross surface area and gross volume of the structure are 6,400 m2 and 24,500 m3, respectively. Depending on the year, there are between 380 and 400 students enrolled, while the adult population, which includes teachers and caregivers, ranges from 40 to 50. (Zinzi et al., 2014)

The structure consists of up of the gym hall and the main school block, which are connected by a shared entrance. The main block is arranged in a classic "L" configuration, with a corridor on one side and classrooms on the other. The hallway connecting the offices and rooms is in the administration area. Figure 3 shows the ground floor plan. There are four stories in the school building: Only a portion of the basement floor is used; it houses the canteen, technical and music laboratories, and an unheated space with a high air exchange rate. Administration rooms, laboratories, and classrooms are located on the ground floor. The ground floor houses the former caretaker apartment as well. Senior citizens now use this apartment for leisure purposes. Classrooms are located on the first and second floors, with a double-height music/meeting hall on the first floor. The hallway and the changing rooms make up the gym. (Zinzi et al., 2014)

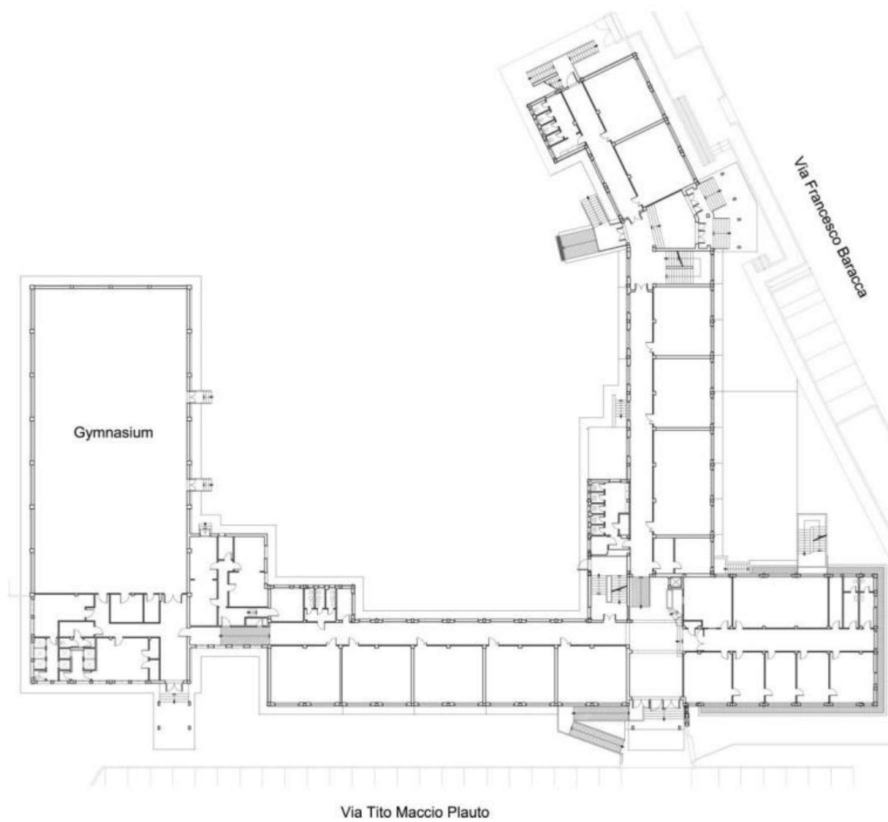


Figure 3 School ground floor (North up) (Zinzi et al., 2014)

The structure was constructed almost forty years ago, and its architecture represented the standard of that era. The exposed reinforced concrete structure is in place. Bricks are laid in two layers without any insulation to create vertical walls. Most of the facade was composed of exposed concrete and brickwork, or cortina as the technology is known in Italy; a small portion was plastered. Single-glazed windows with thin iron frames let in a lot of natural light but did not perform well in terms of insulation. For both visual and thermal comfort, windows were outfitted with manually operated interior venetian blinds. High air permeability was another feature of windows, which led to significant air infiltration rates. (Zinzi et al., 2014)

Figure 4 An example of the building facade, with the above-described components. (Zinzi et al., 2014)

Design criteria and measure.

An analysis of the current state of conditions was the starting point for the energy measures, which were designed to maximize the most essential energy service—space heating. Steps were taken to improve the air tightness and insulation of the building and to upgrade the heating system.

The installation of new windows, attic floor insulation, ground floor insulation (limited to the area that corresponds to the unheated basement space), and insulation of the school's exterior walls facing north and west as well as the gym's entire wall were all chosen as ways to increase energy conservation. The energy targets would have been barely met, according to the first computation results using these theories, thus it was decided to insulate every structure on the school's façade, including the walls facing east and south. Although this solution came with a larger price tag, it was thought to be essential to reduce the possibility that project requirements would not be met during the operational phase. (Zinzi et al., 2014)

Another step taken was installing PV panels on the building's roof thanks to a national financial scheme. The type of PV panels is mono-crystalline silicon photovoltaic, and it is estimated to have 64.68 kWp power. Since the roof is tilted by design panels are placed without need of other equipment to tilt. Estimated energy production of PV panels is 72,300 kWh yearly. With all these improvements and calculations regarding the building's previous energy use, it remains energy neutral. (Zinzi et al., 2014)

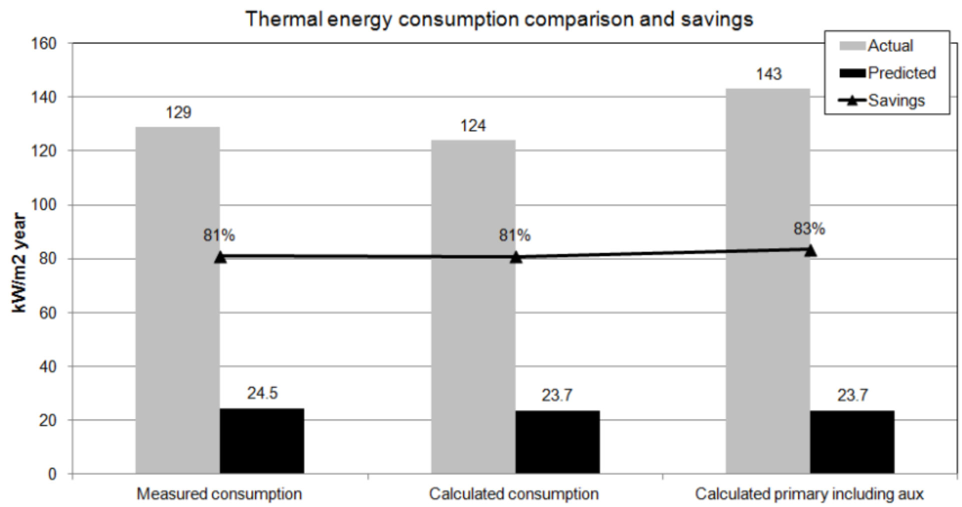


Figure 5 Predicted and measured energy consumption and savings (Zinzi et al., 2014).

The graph provides a detailed comparison between actual and predicted thermal energy consumption, focusing on three categories: measured consumption, calculated consumption, and calculated primary energy use including auxiliary energy. In each case, there is a significant reduction between the actual energy consumption values and the predicted ones. For measured consumption, the actual value is much higher than predicted, but the savings achieved are substantial, resulting in an 81% reduction. Similarly, for calculated consumption, the savings remain consistent at 81%, with actual values again significantly exceeding predicted figures. For the calculated primary energy consumption, which also includes auxiliary energy, the actual usage is the highest, but the savings percentage increases slightly to 83%, reflecting improved efficiency in this area as well. (Zinzi et al., 2014)

Overall, the graph highlights substantial energy savings, with reductions exceeding 80% in all categories. The data underscores the effectiveness of energy-saving measures in reducing thermal energy consumption, with the predicted values much lower than actual consumption, leading to major improvements in energy efficiency.

The first large-scale school building renovation project in Italy is the Tito Maccio Plauto school in Cesena. To incorporate energy-saving measures and provide a suitable environment for building users—especially students—several technicians were involved in the building's design and construction. The work was difficult since it required major improvements to the building envelope, a total overhaul of the heating system, and the installation of new mechanical ventilation systems. (Zinzi et al., 2014)

- **The secondary school Cino da Pistoia , Pistoia ,Italy**

The school building is located at city of Pistoia, which is in the Tuscany area in Italy, is home to Cino da Pistoia. It is a part of an existing school complex that also has a gymnasium, a school canteen, and the elementary school "G. Galilei." On this example building demolition and reconstruction into a new school consisting of two-story buildings (buildings 1 and 2) joined by a solar greenhouse (building 3) was planned.

Building three serves as the entryway to the common areas and the vertical connections that provide access to the various floors, while Buildings 1 and 2 house classrooms and laboratories.

The new school was designed using design strategies for the building envelope and plant systems that satisfy the minimal standards for building energy efficiency in accordance with the Italian CAMs regulation. Consequently, consideration was given to the building's life cycle effects on the environment as well as to the residents' overall comfort, health, and indoor environmental quality (IEQ). (Romano et al., 2023)

Figure 6 Render of the new secondary school "Cino da Pistoia", south façade (Romano et al., 2023).

Design criteria and measure.

A light steel frame structure was used to construct the building to lessen its impact on the environment and ensure reversibility at the end of its life cycle. Furthermore, the school "Cino da Pistoia" was built to meet nZEB (Nearly-zero energy buildings) aims by meeting high sustainability and energy efficiency criteria in accordance with national laws and EU directives. Because of this, throughout the hours of the educational activities, the laboratories and classrooms were facing southeast to benefit from solar gains during the winter. The bioclimatic greenhouse, which depicts the morning solar radiation exposure of the same classrooms, also used similar passive measures to lower the building energy required for winter heating. The transparent volume's movable windows and the shading devices outside the glass façade ensured a reduction in the overheated summer months (Romano et al., 2023).

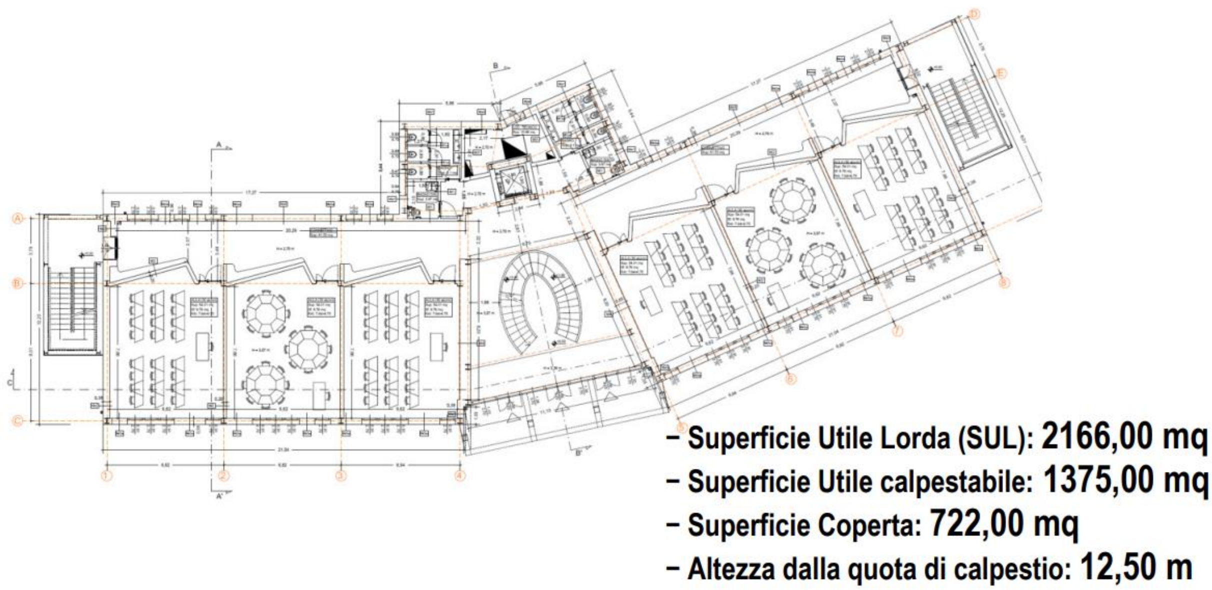


Figure 7 Plan of the ground floor (Romano et al., 2023).

Table 1: Thermal performances of building envelope components.

Building Envelope	Thermal Transmittance [W/m²K]	Indoor Thermal capacity [kJ/m²K]	Periodic Thermal Transmittance [W/m²K]
Wall	0.17	49.57	0.02
Windows	1.20	-	-
Floor	0.12	63.64	0.00
Rooftop	0.23	65.83	0.01

Figure 8 Thermal Performances of the building envelope components of school 'Cino da Pistoia' (Romano et al., 2023).

The school building design project in Pistoia was created utilizing a simulation-based optimization method to assess the design solution's efficacy on energy performance and user comfort indoors throughout the design phase. The advantages of incorporating a ventilated façade over a layered dry facade are demonstrated by the analysis and dynamic simulations used to investigate the highly insulated building envelope. In terms of energy efficiency, the school building's energy performance index for cooling is 15.20 kWh/m2, meeting the target nZEB (Nearly-zero energy buildings. Regarding thermal comfort, the vented façade can improve the PMV index (predicted the mean value) by bringing it closer to the state of thermal neutrality, with a drop of 0.5°C when compared to plaster solution. The average inside temperature can be lowered by 1°C to 2°C, depending on the season. In addition, the thorough daylighting quality of the interior spaces in a few chosen classrooms validated the efficacy of every design strategy pertaining to raising the glazing to floor area ratio and adding a new horizontal reflective screen to windows to block excessive solar radiation light. Lastly, this design demonstrates how the use of simulation tools enables designers to evaluate a new building's energy and environmental performance from the implementation to the usage phases in tandem with its geometric and formal qualities (Romano et al., 2023).

- **The primary school "A. Moro, Seregno, Italy**

The municipality of Seregno is one of the largest cities that had significant development between the 1980s and 1990s and is situated close to Milan between the provinces of Monza and Brianza. Most of the city's growth occurred in the 1990s, and because of the low insulation levels mandated by the national energy laws of 1976 and 1991, the quality of building energy performance cannot be regarded as excellent. For public buildings constructed during that time, one can anticipate thermal transmittances of 0.8 to 0.6 W/m2K for vertical opaque envelopes and 3.5 W/m2K for transparent surfaces. (Tagliabue et al., 2018)

Built in 1973, Aldo Moro School is a single-story building with certain rooms situated on a mezzanine level. The area of the school is 6683 m2. There are seven workshops and 13 classrooms. There are twenty-five pupils in each classroom, and there are 18 in each workshop. For students with disabilities, there are a total of 457 students, forty-one teachers, and 10 assistant teachers. (Tagliabue et al., 2018)

Figure 9 Entrance of the primary school "A. Moro (Tagliabue et al., 2018)

Design criteria and measure.

The teaching spaces of the primary school "A. Moro" are arranged traditionally, but it has been updated with new windows to improve the transparent envelope's thermal performance and an insulating layer to improve the opaque envelope's resistance to heat. There are two main blocks of the building that house various applications. The classrooms are on the north side, and the gym, offices, auditorium, and canteen are on the south block. (Tagliabue et al., 2018)

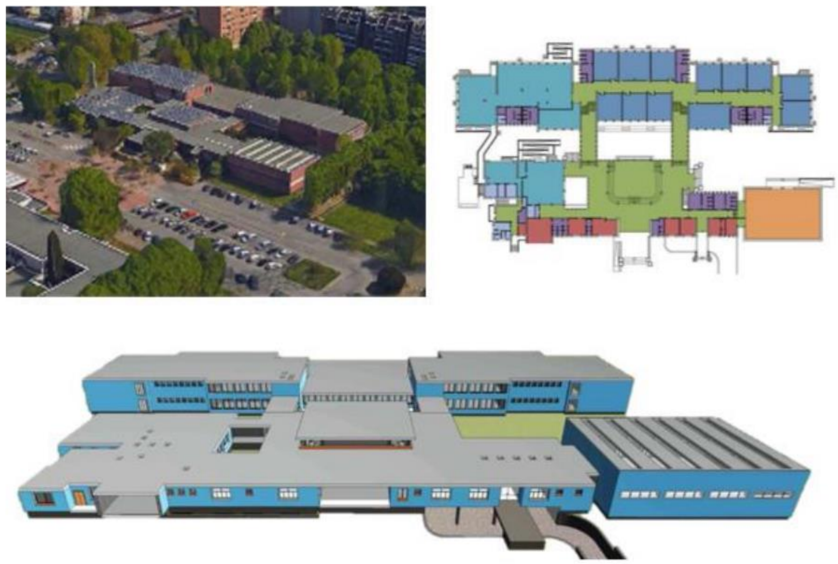


Figure 10 View of the Primary School “A. Moro”, floor area with functional spaces and BIM model

The original envelope configuration and the renovated one were both included in the BIM model that served as the foundation for the modeling process. The renovation was concentrated on improving the transparent and opaque envelope's energy performance. The treatments in question have been the replacement of the windows and the addition of an insulation layer made of polystyrene to strengthen the opaque envelope's resilience. (Tagliabue et al., 2018)

An assessment of the traditional school's energy use Although a standard setting for the indoor area has been adopted, the energy gave monthly results consistent with the real energy bills in the case of the "A. Moro" school, which has a typical layout arrangement. The statistics on internal gains, population density, ventilation rates, temperature set points, and timetable that are included in the standard setup are obtained from values that are widely accepted for the use of historic buildings. (Tagliabue et al., 2018)

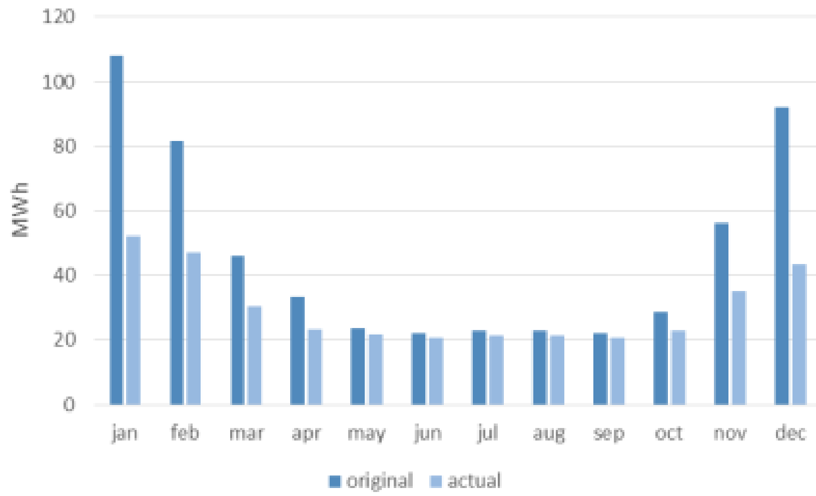


Figure 11 Primary school "A. Moro": energy consumption simulation of in the original situation and the retrofitted version.

The graph compares the original projected energy consumption (in MWh) with the actual energy consumption for each month of the year. In most months, the actual consumption is lower than the original projection. January and December show particularly high energy usage in both the original and actual figures, with the actual consumption in January exceeding 100 MWh and in December approaching similar levels. During the summer months (June to August), both original and actual consumption are relatively lower and more consistent. However, significant differences between original and actual values can be seen throughout, indicating improvements in energy efficiency. (Tagliabue et al., 2018)

After looking of examples of educational buildings in Italy that been built more than 40 years ago, it has been analyzed using a sustainable and energy efficient design methodology, the following assessment of these facilities' suitability for sustainable design is made:

1) Assessments for the Tito Maccio Plauto school, Cesena, Italy,

- Air tightness improvement: Enhancing the building's air tightness to prevent heat loss.
- Installation of PV panels on to the roof.
- Insulation upgrades: Adding insulation to various parts of the building, including:
    - Attic floor insulation.
    - Ground floor insulation (limited to areas above the unheated basement).
    - Insulating the exterior walls facing north and west, and the gym's entire wall.
    - Full façade insulation, including walls facing east and south.
- Heating system upgrade: Modernizing the heating system to increase efficiency.
- New windows installation: Replacing old windows with energy-efficient ones.
- Façade insulation: Expanding insulation to all sides of the building to meet energy targets and ensure long-term performance. (Zinzi et al., 2014)

2) Assessments for the secondary school Cino da Pistoia, Pistoia, Italy,

- Simulation-based optimization: Used to evaluate energy performance and indoor comfort throughout the design phase.
- Ventilated façade: Chosen over a layered dry façade to improve energy efficiency and thermal comfort.
- Highly insulated building envelope: Enhances energy conservation and thermal performance.
- Energy performance: Achieved a cooling energy performance index of 15.20 kWh/m², meeting nZEB (Nearly Zero-Energy Building) standards.
- Improved thermal comfort:
    - Ventilated façade enhances the PMV (Predicted Mean Vote) index, bringing it closer to thermal neutrality.
    - Lowers indoor temperatures by 0.5°C to 2°C, depending on the season.
- Daylighting strategies:
  - Increased glazing-to-floor area ratio to enhance natural lighting.
  - Installed horizontal reflective screens to windows to reduce excessive solar radiation.

- Use of simulation tools: Enabled evaluation of energy and environmental performance in tandem with geometric and design features from implementation to the usage phase (Romano et al., 2023).
- 3) Assessments for the primary school "A. Moro, Seregno, Italy
  - Improved transparent envelope: Replacement of old windows with new ones to enhance thermal performance.
  - Improved opaque envelope: Addition of an insulation layer made of polystyrene to increase the building's resistance to heat loss.
  - BIM model integration: Both the original and renovated envelope configurations were incorporated into the comprehensive Building Information Model (BIM) to guide the modeling process.
  - Zoning of functional spaces: The building is divided into two main blocks:
    -North block: Classrooms.
    -South block: Gym, offices, auditorium, and canteen.
  - Energy performance assessment: Monthly energy consumption data aligned with real energy bills, using widely accepted standards for internal gains, population density, ventilation rates, temperature set points, and timetables for historic buildings. (Romano et al., 2023)

❖ **Evaluations Sustainable Approaches in Educational Buildings in Italy**

The common elements between the assessments of the Tito Maccio Plauto School (Cesena), Cino da Pistoia Secondary School (Pistoia), and A. Moro Primary School (Seregno) are:

- Envelope insulation: All three schools focused on improving the thermal insulation of the building envelope, including both the transparent (windows) and opaque (walls, floors, ceilings) parts, to enhance energy efficiency and reduce heat loss.
- Window replacements: Each project involved the installation of new, energy-efficient windows to improve thermal performance and minimize heat loss through the transparent envelope.
- Air tightness and thermal comfort: Enhancing the building's air tightness and focusing on thermal comfort were key measures. In the Tito Maccio Plauto and Cino da Pistoia schools,

improving air tightness was essential for preventing heat loss, and in the Cino da Pistoia school, the ventilated façade contributed to improved thermal comfort and air quality.

- Energy efficiency targets: All three schools aimed at improving energy efficiency, with specific targets like meeting nZEB standards (Cino da Pistoia), reducing energy consumption through insulation (Tito Maccio Plauto), or aligning energy consumption with real energy bills (A. Moro).
- Heating system upgrades: Schools upgraded or modernized their heating systems to further improve energy efficiency and reduce operational costs.
- Façade insulation: Insulation was a priority in each school, whether through full façade insulation (Tito Maccio Plauto), ventilated façades (Cino da Pistoia), or enhanced insulation layers (A. Moro).
- Use of modeling and simulation tools: Schools utilized BIM or simulation tools to assess the energy performance and environmental impacts, guiding the design and renovation process.

These measures emphasize a strong focus on energy efficiency, thermal comfort, modernizing building systems, and employing technological tools for optimized building performance across the three schools. (Zinzi et al., 2014; Romano et al., 2023 ; Tagliabue et al., 2018)

2.2 Energy Efficiency

Over the past decade, various organizations have concentrated on tackling climate change and reducing carbon emissions, with a strong focus on enhancing energy efficiency as a key strategy for mitigating environmental impact.

The IEA (International Energy Agency, n.d.) is an autonomous organization that works to promote energy security, economic growth, and environmental sustainability. Established in 1974, it provides policy advice, data analysis, and technical assistance to member countries on energy issues. The IEA also plays a key role in promoting clean energy technologies and advancing energy efficiency measures globally, helping nations transition to more sustainable energy systems. It supports global efforts to address climate change and reduce carbon emissions.

The Intergovernmental Panel on Climate Change (IPCC) is a scientific body established by the United Nations (UN) and the World Meteorological Organization (WMO) in 1988. Its primary goal is to assess the scientific knowledge about climate change, its impacts, and potential future risks, and to provide policymakers with objective, reliable information on global climate issues.

The IPCC produces assessment reports that synthesize the latest scientific research on climate change, focusing on the physical science of the atmosphere, its impacts on ecosystems and human systems, and strategies for mitigation and adaptation. The panel's work helps guide international climate policies, including those within the UN Framework Convention on Climate Change (UNFCCC) and the Paris Agreement.

The IPCC's assessments are based on peer-reviewed scientific literature and are written by hundreds of experts from around the world. These reports are widely considered the most authoritative sources of climate knowledge.

2.2.1 Energy Efficiency in Buildings

According to the Energy Performance of Buildings Directive (EPBD), buildings are responsible for around 40% of energy consumption in the European Union and more than a third of its energy-related greenhouse gas emissions. A significant portion of energy used in homes—approximately 80%—goes toward heating, cooling, and hot water demand. This highlights the importance of improving building energy performance to reduce overall consumption and emissions, contributing to sustainability and climate goals.

The Energy Performance of Buildings Directive (EPBD) sets standards for the energy performance of buildings, requiring them to meet specific energy efficiency criteria. It mandates the use of energy performance certificates (EPC) for buildings, which measure their energy consumption and offer recommendations for improvements. The directive emphasizes reducing energy demand and promoting the use of renewable energy sources in buildings, aiming to improve the overall energy efficiency of the European building stock.

Advancements in construction technology have enabled the integration of energy-saving measures into building design to boost comfort, efficiency, and aesthetic appeal. Over recent decades, researchers have developed innovative solutions for thermal design that support energy conservation. Despite variations in style, energy-efficient buildings share common features, such as high-quality insulation for walls, windows, and doors; an airtight building envelope; ventilation systems with heat recovery; and high-efficiency heating and cooling systems. Solar technologies and energy-efficient appliances are also integral components. Furthermore, currently on the market various affordable insulation materials are available. Selecting the right materials and solutions for each building's specific requirements is crucial to achieving cost-effective energy efficiency. This tailored approach ensures that the energy-saving measures are both effective and economically feasible for a range of building types (Ionescu et al., 2015)

The global reduction of CO2 emissions is crucial to mitigating climate change. Lowering energy consumption in major sectors is the most direct approach to reducing greenhouse gas emissions. The European Directive established in 2007 set three primary targets, using 1990 as a reference year: a 20% reduction in emissions, a 20% increase in energy production from renewable sources, and a 20% improvement in energy efficiency. With its high potential for energy efficiency, the building sector has become a focal point. In response, the European Commission issued Directive 2010/31/EU on May 19, 2010, to ensure buildings meet energy performance standards, with supplementary directive 244/2012 detailing cost-optimal design assessments. (Ionescu et al., 2015)

2.2.2 Energy Performance of Buildings Directive (EU/2024/1275)

The latest revised Energy Performance of Buildings Directive (EPBD), officially known as Directive (EU) 2024/1275, sets forth new requirements aimed at enhancing energy efficiency within the EU building sector. Effective as of May 2024, the directive mandates that all new buildings must achieve zero-emission status by 2030. For public buildings, this target is advanced to 2028. By 2050, all buildings, including existing structures, are expected to meet zero-emission standards.

Key updates in the directive include provisions for "Building Renovation Passports" by 2026, encouraging gradual energy-efficiency improvements through structured renovation plans. The directive also introduces requirements for integrating solar installations on certain building types and extends financial incentives for energy-efficient renovations. Additionally, Global Warming Potential (GWP) metrics will be integrated into energy performance certificates by 2028 for new buildings over 1000 m² and by 2030 for all new structures. This certificate revision will help building owners make informed choices by clearly showing environmental impacts. (Energy Performance of Buildings Directive, n.d.)

2.2.3 CAM The Minimum Environmental Criteria (I Criteri Ambientali Minimi)

The **Criteri Ambientali Minimi (CAM)**, or Minimum Environmental Criteria in English, are regulations established in Italy to promote environmental sustainability in construction and public procurement. CAM aims to set minimum environmental standards for various building projects, ensuring that construction practices align with ecological and health considerations.

The CAM requires the use of construction materials that minimize environmental impact throughout their life cycle. This includes preferences for recycled materials, low-emission products, and those sourced locally to reduce transportation emissions, also aim to improve indoor environmental quality (thermal, acoustic, and visual comfort), support recycling and recovery of materials, and enhance the integration of green spaces in urban settings. Another aspect of CAM is to encourage consideration of lifecycle costs in public contracts, including energy consumption and waste management, to promote long-term sustainability.

CAM also mentions about If a project is being evaluated for certification under recognized sustainable building certifications (like LEED, BREEAM or WELL), meeting the CAM criteria can be demonstrated through certification process. (I CRITERI AMBIENTALI MINIMI., 2022)

2.2.4 Energy Performance Certificate (APE)

The APE (Attestato di Prestazione Energetica) is an Italian energy performance certificate that assesses the energy efficiency of buildings. It is mandatory in Italy for properties being rented, sold, or undergoing major renovations. The certificate assigns a building an energy rating, typically from A4 (most efficient) to G (least efficient), and provides recommendations for improvements. The APE is valuable for identifying ways to reduce energy consumption, lower utility bills, and increase property value.

The APE became mandatory in Italy starting in 2005 with the introduction of Legislative Decree 192/2005. This regulation was aligned with the European Directive 2002/91/EC on the energy performance of buildings. The requirement was further reinforced with the adoption of the 2010 Legislative Decree 63/2010, which made the APE mandatory for property sales, leases, and significant renovations.

The APE is calculated based on a building's energy consumption, considering factors like insulation, heating, cooling, and hot water systems. The calculation uses a method outlined in Italy's national regulations (UNI/TS 11300), assessing energy use for different seasons. A certified energy expert conducts the evaluation, typically using specialized software to ensure compliance with Italian laws. This process leads to an energy class rating, from A4 (most efficient) to G (least efficient).

In Italy, calculating the APE (Certificazione energetica APE, n.d.) involves specialized softwares that complies with national standards, specifically UNI/TS 11300 and related norms. Some of the most commonly used applications will be explained down below among their features and differences.

Applications that will be explained in detail are Termolog, Blumatica, Docet, Acca Termus and Edilclima.

A) Termolog

Termolog is a specialized software used for energy efficiency analysis, thermal performance simulations, and building systems design. It helps architects and engineers evaluate a building's heat loss, energy consumption, and the performance of heating and cooling systems.

Termolog also enables simulations for renewable energy systems, allowing users to assess how solar and thermal panels affect a building's energy performance. It includes tools to evaluate environmental and economic factors, providing insights into the material costs and overall environmental impact of various energy-saving solutions.

Termolog includes AI-assisted validation to ensure compliance with regulations. It is compatible with BIM platforms like Revit and CAD designs, allowing for seamless integration with design workflows. This compatibility enhances project efficiency, particularly for energy analysis and sustainable development, ensuring a streamlined process for architects and engineers working with BIM technology (Termolog, 2024).

While the APE calculation follows national UNI/TS 11300 standards, it is also compatible with the specific regional laws of Lombardia (Termolog, 2024).

B) Blumatica

Blumatica APE is a software designed for energy performance certification in buildings. It helps users calculate the energy class of a building according to the national regulations. Key features include automatic APE generation based on building parameters, calculation of heating, cooling, and energy consumption, generation of reports for compliance with energy laws, support for energy-saving suggestions and compatibility with building renovation projects. (Blumatica, n.d.)

Blumatica also can assess how photovoltaic systems meet the electricity needs of the various services. (Blumatica, n.d.)

It is compatible with CAD drawings. By drawing or importing a plan, you automatically obtain, for each room, the identification of surfaces and volumes, shading angles, orientations and surfaces of the dispersing elements (internal and external walls, floors and roofs, external and internal fixtures, etc.), thermal bridges. (Blumatica, n.d.)

Blumatica is simple and more affordable than some other options, which makes it accessible for smaller firms or projects with limited budgets. Its functionality is basic, so it may not be sufficient for complex energy simulations or detailed dynamic analyses.

Blumatica APE does offer some level of economic evaluation, particularly focused on assessing the financial aspects related to energy efficiency measures, such as the cost-effectiveness of potential energy-saving improvements. However, its economic analysis is limited.

Blumatica APE follows the national UNI/TS 11300 standards for calculating energy performance in buildings, ensuring that it aligns with Italy's energy regulations. However, it is not specifically tailored to the regional laws in some areas, meaning it may not fully comply with unique regional requirements in places like Lombardia or Piemonte. This limitation could affect its application in certain projects where precise regional compliance is required. (Blumatica, n.d.)

C) Docet

DOCET APE is a software designed for calculating the energy performance of residential buildings. It is primarily used for small-scale projects up to 200 square meters, offering a straightforward method for generating APE certificates. DOCET provides tools for evaluating heating systems, energy consumption, and compliance with energy regulations, but its capabilities are more limited compared to more advanced programs. It does not support extensive or complex projects and may lack some of the advanced features found in other software options. It's commonly used for quick, basic assessments. (Docet, 2024)

DOCET APE does not natively integrate with CAD or BIM platforms. It is designed for simpler, small-scale residential projects and does not offer the advanced BIM compatibility found in other energy certification software. Its focus is primarily on providing a straightforward tool for APE calculations without supporting complex integrations commonly used in larger or more detailed architectural projects. (Docet, 2024)

DOCET APE follows national energy performance regulations, specifically the UNI/TS 11300 standards, for calculating the energy class of buildings. However, it does not have the capability to comply with specific regional laws. (Docet, 2024)

DOCET APE does not offer an economic evaluation feature. Its primary function is to calculate the energy performance of buildings for certification purposes. DOCET APE does not support detailed simulations for renewable energy systems, such as solar or thermal panels. It focuses primarily on energy performance calculations for heating, cooling, and energy consumption, without advanced features for simulating or integrating renewable energy technologies. (Docet, 2024)

D) Acca Termus

Termus by ACCA is a software solution for calculating the energy performance of buildings in Italy, specifically designed to generate the APE (Attestato di Prestazione Energetica). It adheres to national UNI/TS 11300 standards and includes tools for evaluating heating, cooling, and energy consumption.

Termus also supports simulations for renewable energy systems, such as solar panels and thermal systems, and is designed to help professionals with energy audits and compliance. It also features an automatic report generation system and is compatible with other ACCA software. (ACCA, n.d.)

Termus supports economic evaluation by calculating the cost-effectiveness of energy-saving interventions. It allows users to assess potential savings from energy efficiency improvements, including the financial impact of implementing renewable energy systems. This feature helps architects, engineers, and energy professionals evaluate the cost-benefit ratio of various building upgrades in terms of both energy consumption and economic performance. (ACCA, n.d.)

ACCA follows the national UNI/TS 11300 standards for energy performance certification. It ensures compliance with Italian regulations for calculating APE (Energy Performance Certificate) and supports the energy performance calculation for buildings in line with Italy's building energy law requirements.

It is also compatible with the specific regional laws of Emilia Romagna, Lombardia and Molise. (ACCA, n.d.)

Lastly, ACCA is compatible with BIM systems, allowing integration with 3D models to streamline energy performance simulations and calculations. (ACCA, n.d.)

E) Edilclima

Edilclima is a specialized software suite designed to support energy efficiency analysis, building systems design, and thermal performance simulations, widely used in architecture and engineering for sustainable and energy-efficient building design. Edilclima allows users to perform detailed energy assessments by calculating heating and cooling loads, analyzing thermal transmittance, and evaluating energy requirements for buildings. It supports compliance with European and Italian regulations for energy performance, such as those related to building envelope insulation, HVAC systems, and renewable energy integrations. (*Edilclima*, n.d.)

The software helps in designing and sizing mechanical systems, including HVAC, hydronic systems, solar thermal installations, and photovoltaic systems. This is particularly useful in sustainable architecture, where optimizing system sizes can improve energy efficiency and reduce costs. (*Edilclima*, n.d.)

Edilclima also supports simulations for renewable energy systems, enabling architects and engineers to model the impact of solar panels, and other renewable sources on a building's energy performance. It provides tools to analyze environmental and economic factors, offering insights into lifecycle costs and the overall environmental impact of different energy-saving solutions. (*Edilclima*, n.d.)

While the APE calculation follows national UNI/TS 11300 standards, it is also compatible with the specific regional laws of Lombardia, Piemonte, and Emilia Romagna. This ensures that the calculations meet the local regulations and requirements for energy performance in these areas.

Edilclima is also compatible with BIM (Building Information Modeling) platforms, which means it can integrate with design software Revit to streamline workflows in projects that use BIM for sustainable development and energy analysis such as tools like EC770. (Edilclima, n.d.)

F) Evaluations of APE calculation applications

In the previous section, the applications were thoroughly explained, covering their functions, regulations, strengths, and weaknesses. To better highlight their differences and assist in selecting the most suitable software for the case study, the following table has been created for comparison.

APE Calculation Application	Project Size Constrains	Supports National UNI/TS 11300	Provides Economic Evaluation	Provides BIM integration	Compliance with Piemonte Regional Laws
Termolog	No	Yes	Yes	Yes	No
Blumatica	No	Yes	Limited	No	No
Docet	Yes	Yes	No	No	No
Acca Termus	No	Yes	Yes	Yes	No
Edilclima	No	Yes	Yes	Yes	Yes

Table 1 Comparison of APE calculation Applications

Table above shows comparison of APE calculation applications for various factors. The first factor to consider is whether the software applications have any constraints regarding the size of projects they can support. It can be noted that Docet has a significant limitation, as it cannot handle projects larger than 200 square meters. This size restriction makes it not suitable for the case study. (Docet, 2024)

The second factor is whether the application supports National UNI/TS 11300 law. As can be seen from the table all of the applications support the law.

The third column highlights whether the applications offer economic evaluation for the APE calculations. As observed, Termolog, Acca Termus, and Edilclima provide economic evaluation features. In contrast, Blumatica offers only a limited economic evaluation, while Docet does not include any economic evaluation functionality at all.

Next factor that taken into account it whether applications provide BIM integration or not. Information from the table shows that Blumatica and Docet programs do not offer alliance with BIM programs.

The final feature in the table addresses compliance with regional laws in Piemonte. Since the case study is located in this region, adherence to local regulations is crucial. As shown in the table, Edilclima is the only application that ensures full compliance with Piemonte regional laws.

2.3 Building Information Modelling

The architecture, engineering, and construction (AEC) industry has been searching for methods to reduce project costs, enhance productivity and quality, and shorten project delivery times. Building Information Modeling (BIM) presents a promising solution for achieving these goals (Azhar, 2011). With the acceptance of BIM building industry has been changed. BIM is a three-dimensional geometric model filled with extensive data. The information within it can serve various purposes, such as forecasting energy consumption, assessing structural performance, estimating costs, scheduling, detecting system conflicts before construction, and even supporting facilities management tasks. (Kensek, 2014)

BIM is a process that engages a wide range of stakeholders, from design and construction to operations and maintenance. It promotes collaboration by encouraging the sharing of data, knowledge, responsibility, risks, and rewards. While it supports integrated project delivery (IPD), it also adds value to projects with other contract types, such as design–bid–build, design-build, and construction manager at risk. (Kensek, 2014)

BIM allows for the simulation of construction projects within a virtual setting. Utilizing BIM technology, a detailed virtual representation of a building, referred to as a building information model, is created digitally. Once completed, this model includes accurate geometry and pertinent data necessary to facilitate the design, procurement, fabrication, and construction processes required for the building's realization (Eastman, 2008)

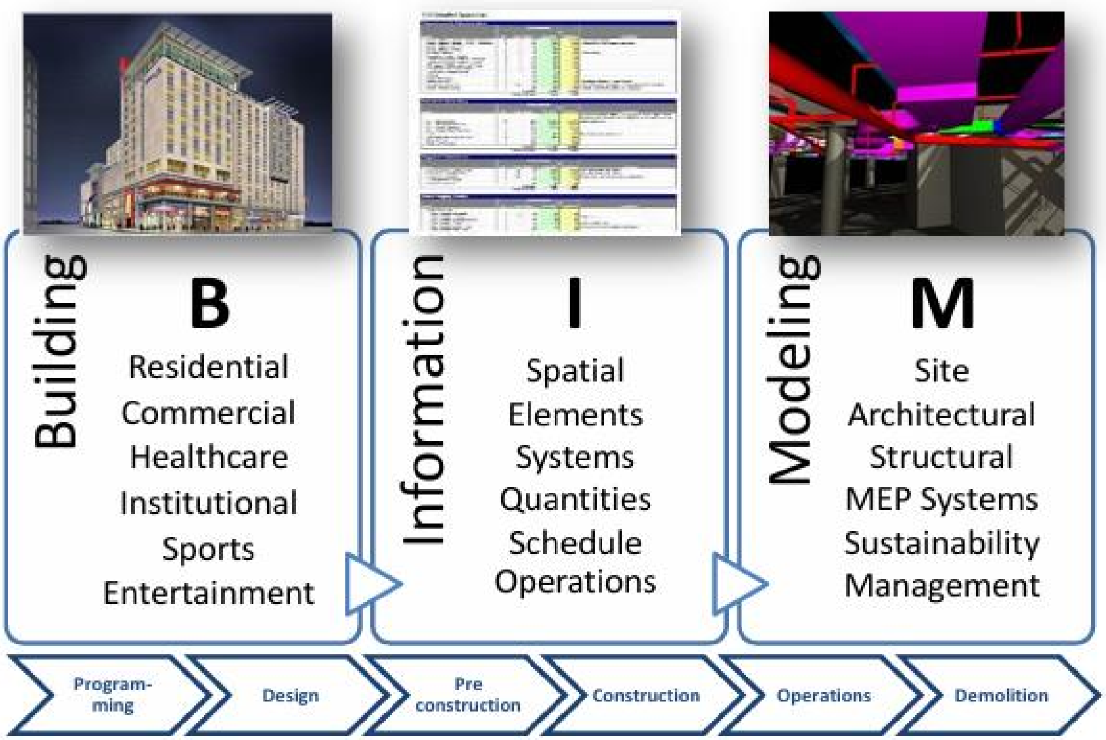


Figure 12 A Visual Representation of BIM Concept (Azhar et al., 2015)

In the early stages of a construction project, BIM provides valuable insights on material quantities, detailing the volumes and weights of building components such as structural columns, load-bearing walls, and slabs, as well as information on the energy properties of insulation materials and the type of heating and air-conditioning systems (Lahiani, 2020). Also, Contractors can use building information models to conduct precise quantity surveys and create detailed cost estimates (Azhar et al., 2015).

BIM in the design phase also can be utilized for its benefits, in conventional 3D CAD, a building is depicted through separate 2d or 3D views, such as floor plans, sections, and elevations. However, these views are not automatically linked. If there is a change in one of the views, the rest of the views must be updated manually, making CAD drawings prone to mistakes. In CAD, the drawings consist only of graphical elements, like lines, arcs, and circles. They represent parts of a building but don't convey any information about the function or context of these parts. For instance, a CAD drawing might show a wall as a series of lines, but it doesn't recognize it as a "wall" with specific properties or a role in the building. In contrast in BIM, models are created with "intelligent" objects—meaning that each component is defined as a specific element in the building, like walls, columns, or spaces. These objects have contextual information and can interact with each other as they would in a real building. BIM goes beyond just geometry. Each object in the model carries extensive information about the building's physical and functional characteristics, as well as lifecycle details. (Azhar et al., 2015)

The primary advantage of in the post construction phase is that BIM model delivers detailed information on a building's spaces, systems, and components, with the ultimate aim of integrating this data into facility management operations (Azhar et al., 2015).

Azhar (2011) explains the risks of using BIM into two categories regarding legal (or contractual) and technical issues. A primary legal risk is defining ownership of BIM data and protecting it through copyright laws. If the project owner finances the design, they may feel entitled to own the BIM data. However, if team members contribute proprietary information, their data needs protection. Each project requires a unique approach to ownership to avoid deterring full participation in the model's use (Thomson & Miner, 2006). The most effective way to prevent copyright disputes is to clearly define ownership rights and responsibilities within the contract (Rosenberg, 2007). When project contributors beyond the owner and architect/engineer, such as vendors, add data to the BIM, licensing concerns may arise. For instance, vendors often provide product designs to promote their equipment, but complications occur if those designs are created by non-licensed designers in the project's jurisdiction (Thomson & Miner, 2006)

When it comes to technical issues, cost and scheduling elements are added to a BIM model, ensuring compatibility between various software programs becomes crucial. Many contracting teams require subcontractors to submit detailed critical path schedules and itemized cost breakdowns before the project begins. The general contractor compiles this data into a detailed schedule and cost summary. If subcontractors and the prime contractor use compatible software, integration is smooth. However, if data is incomplete or submitted in different formats, a designated team member must re-enter it into a master scheduling and costing tool, which may be a BIM module or a separate program compatible with BIM. Since most project management tools have been developed independently, ensuring the accuracy and coordination of cost and scheduling data must be contractually specified (Thomson & Miner, 2006).

2.3.1 BIM Dimensions

Building Information Modeling (BIM) is a digital work methodology aimed at improving efficiency, collaboration, and sustainability across a building's lifecycle—from design through construction to maintenance. This approach involves creating a centralized model that integrates various data points, including geometry, materials, costs, timelines, and sustainability aspects.

BIM enables collaboration among all project stakeholders, including architects, engineers, and contractors. This shared access to a centralized model minimizes miscommunication and allows for more coordinated decision-making. BIM includes multiple "dimensions" to represent different project aspects, such as 3D geometry, 4D (time/schedule), 5D (cost), 6D (sustainability/energy), and even 7D (facility management). Each element has associated data such as technical specifications and performance metrics (Montiel-Santiago, 2020).

Dimensions BIM	Properties	Aspects Developed in the Model
2D	2D Basic Documentation	Traditional two-dimensional (2D) plans Lines, planes images
3D	3D three-dimensional model	Graphic documentation in three dimensions (3D) Special geometric information Objects with properties 3D visualization of the project
4D	Programming the Execution Plan (Deadlines)	Simulation of Project phases Installations Simulation Design of the execution Plan
5D	Planning, Monitoring and Cost Control	Budget estimate of expenses Measurements of materials and labor Analysis of operating costs
6D	Sustainability and energy efficiency	Energy analysis Envelope variations and interactions Analysis of simulations and energy efficient and environmentally sustainable proposals
7D	Facility Management	BIM Life Cycle Analysis (LCA) Strategies BIM as built Building Operations and Maintenance Plan Model Logistical Control of the Project

Table 2 Dimensions of Building Information Modeling (BIM) for buildings. Table from Montiel-Santiago et al. (2020)

In BIM 6D, the model simulates energy use and environmental performance, helping to optimize sustainable features like lighting, energy efficiency, and renewable energy systems. Beyond construction, BIM supports maintenance planning (BIM 7D), aiding in facility management, renovations, and repairs. (Montiel-Santiago et al., 2020)

2.3.2 Level of Detail (LOD)

Building Information Modeling (BIM) involves creating and managing digital representations of built assets like buildings or infrastructure. BIM encompasses both technical and non-technical project components. The model's level of detail, known as BIM Level of Development (LOD), reflects the stage of design and the data associated with graphical elements. A BIM model evolves from an initial sketch to final as-built drawings, capturing increasing detail over time. Different levels of detail have been explained down below. (Patel, 2024)

LOD 100 Conceptual Design: LOD 100 represents the early stages of building design, offering a simplified and basic geometric model that illustrates the general shape and size of the proposed building. This level of detail is mainly used for initial visualization and feasibility studies. While it does not provide extensive information, LOD 100 models are valuable for initiating design discussions and providing stakeholders with a broad understanding of the project.

LOD 200 Design Development: This level represents a more developed stage of the building design, incorporating refined geometric details such as walls, floors, and roofs. It is more accurate than LOD

100 and plays a key role in design development. This level facilitates collaboration among architects and engineers, helping to refine the building's structure. Additionally, LOD 200 models are used for cost estimation, spatial coordination, and detecting design clashes, making them essential for identifying potential conflicts before construction begins.

LOD 300 Construction Documentation: These models include detailed information necessary for construction documentation. These models represent architectural elements such as doors, windows, and stairs. They serve as the basis for creating precise shop drawings and construction documents. Contractors and subcontractors use LOD 300 models to extract accurate quantities, organize construction sequencing, and coordinate tasks across different trades involved in the project.

LOD 350 Construction Stage: Models are used during the construction stage to provide detailed information on systems, assemblies, and individual components needed for installation. They help with coordination between trades and subcontractors, ensuring components fit properly. These models improve communication on-site, reducing conflicts and enhancing project efficiency, ultimately streamlining the construction process.

LOD 400 As-Built Documentation: Models that capture the as-built condition of a structure post-construction, providing detailed data about installed components, equipment, and systems. These models are essential for facility management, enabling efficient maintenance, repairs, renovations, and future improvements. They ensure that the building operates smoothly and facilitates long-term sustainability by providing accurate, up-to-date information for future modifications.

LOD 500 Facility Management: BIM models integrate data with asset and facility management systems, offering detailed information about building components, including specifications, maintenance schedules, and warranty details. These models are crucial for efficient facility management, aiding in planning and executing maintenance, tracking assets, and optimizing building performance. By utilizing LOD 500, organizations can ensure the smooth operation and long-term sustainability of buildings throughout their lifecycle. (Patel, 2024)

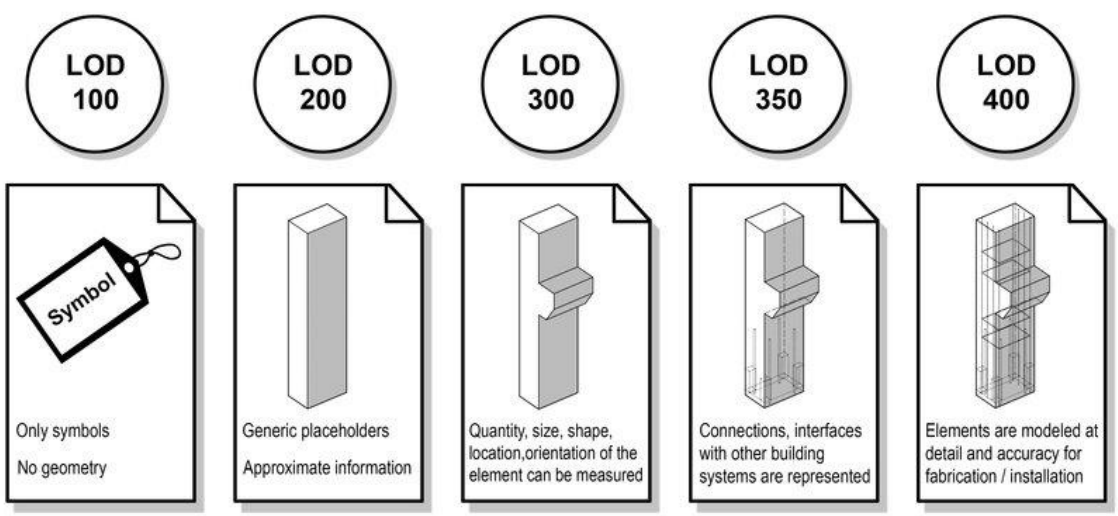


Figure 13 Level of Detail in BIM (Understanding Different Levels of Detail (LODs) in Building Information Modeling (BIM) Models, n.d.)

The figure 13. above illustrates how an element's Level of Detail (LOD) in BIM can be categorized based on the amount and type of information included at different project stages. It depicts a progression in model development, starting with a basic outline of the element's shape and progressing to include intricate details and specific data related to its materials, dimensions, and installation information. (Patel, 2024)

2.3.3 As-Built Modelling

As-built modelling involves creating an accurate representation of the current state of a building, which includes both its geometry and thermal/environmental conditions. This type of modeling is essential for retrofit assessments and energy diagnostics in existing buildings, where having precise data on the current state is critical for making effective and efficient energy improvements. (*3D BIM as built Modeling, 2024).*

As-built models are generated using techniques like laser scanning, photogrammetry, and structure-from-motion to create detailed 3D representations. These models include data on the spatial arrangement and physical conditions of building components. Point cloud data from 3D scans are often converted into Building Information Models (BIM) in formats like gbXML, making it easier to use in various energy modeling tools. (*3D BIM as built Modeling, 2024).*

Figure 14 As-built model example from (3D BIM as built Modeling, 2024).

Provides precise details on the building's current state, which is invaluable for accurate energy and thermal performance analysis. Also, accurate modeling allows for better-informed decisions on retrofit interventions, lowering the risk of costly or ineffective improvements (3D BIM as built Modeling , 2024)

2.3.4 Point Cloud

A point cloud is a set of data points in a three-dimensional coordinate system, representing the 3D surface of an object or environment. Each point in a point cloud has x, y, and z coordinates that specify its position, and sometimes other attributes like color or intensity. Point clouds are typically generated using technologies like LiDAR (Light Detection and Ranging) or photogrammetry and are used to create highly accurate representations of real-world structures, which are essential in Building Information Modeling (BIM) processes. (Abreu, 2023)

The use of point clouds is important because they provide precise, detailed, as-built information on structures, which can help update BIM models to reflect real-world conditions. This is crucial for various applications in Architecture, Engineering, and Construction (AEC). The alignment of point cloud data with BIM models allows for identifying deviations between the planned and actual structures, facilitating timely corrections. (Abreu, 2023)

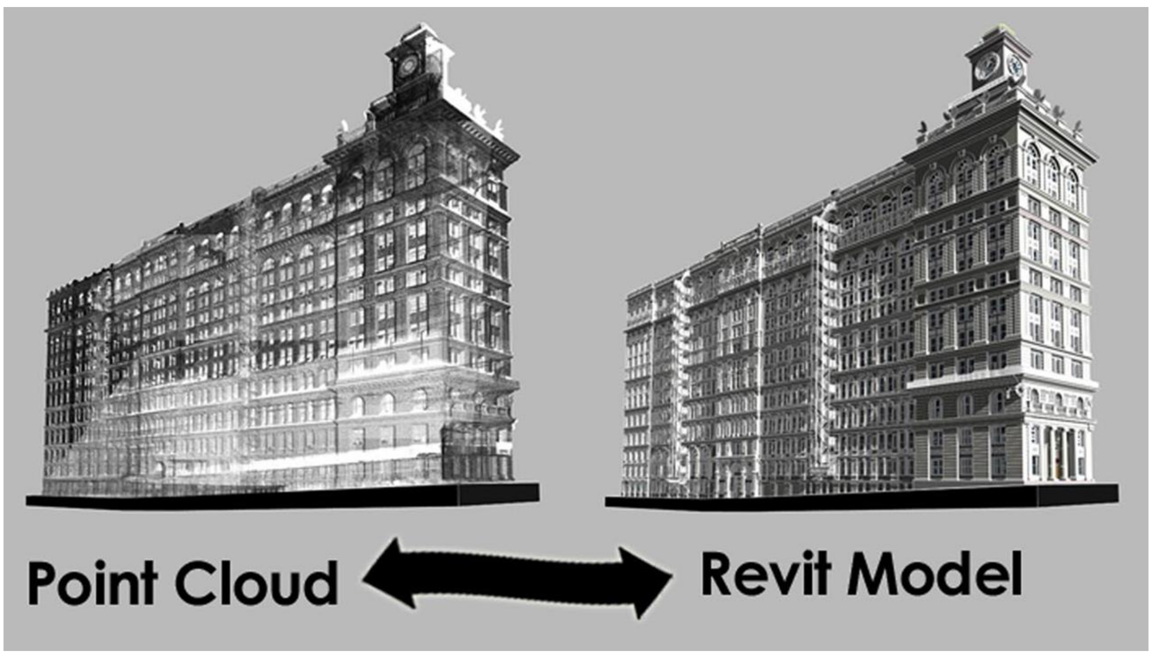


Figure 15 Example of a project turning point clouds to BIM model (POINT CLOUD TO BIM, n.d.)

2.3.5 IFC and BIM Interoperability

Industry Foundation Classes (IFC) is an open, standardized file format developed by buildingSMART International for the exchange of Building Information Modeling (BIM) data across different software platforms. IFC promotes interoperability between various BIM tools, ensuring that project information can be shared seamlessly, regardless of the specific software being used. By providing a common language for BIM data, IFC allows architects, engineers, contractors, and other stakeholders to collaborate effectively, without losing valuable information during data transfers (BIM and IFC - What are IFC models, and how do BIM and IFC relate?, 2023)

In the context of BIM and IFC for interoperability, IFC plays a critical role by enabling diverse teams to work within a unified digital framework. BIM relies heavily on the integration of data from multiple disciplines, and the ability to exchange this data accurately across platforms is essential for successful project delivery. IFC acts as the bridge, ensuring that models created in one software can be accessed and utilized by others, preserving data integrity throughout the lifecycle of a project. (BIM and IFC - What are IFC models, and how do BIM and IFC relate?, 2023). Thanks to IFC various stakeholders can access the same BIM model and exchange information smoothly due to enhanced interoperability. (Eastman, 2008)

3. METHODOLOGY

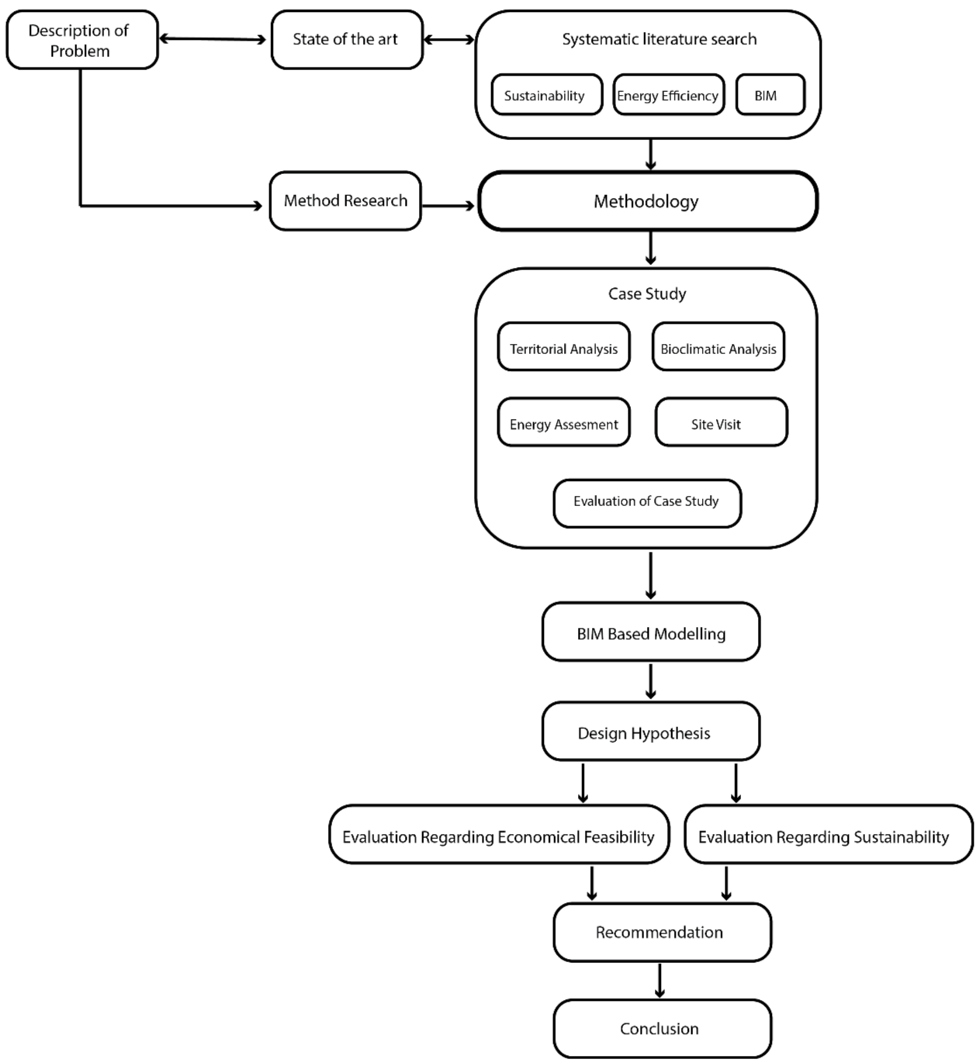


Figure 16 Flow Chart of the Thesis

The flow chart above explains the process of gathering and assessing information for the thesis topic, illustrating the various steps involved in the research process.

According to the most recent data (30/04/2024) from (Anagrafe dell'Edilizia Scolastica, 2024), there are approximately 41,000 educational institutions across the country, spanning primary, secondary, and higher education levels (Anagrafe dell'Edilizia Scolastica, 2024), as cited in (Guarini, Morano, & Sica, 2020). Of these, around 22,000 school buildings were constructed before 1970. Notably, only about 57.5% of these older structures have implemented measures to reduce energy consumption. This thesis examines and evaluates strategies for enhancing energy efficiency in Italian school buildings, with a case study focused on the Amaldi Sraffa high school complex in Orbassano. Built beginning in the 1970s, the "Amaldi-Sraffa" complex includes three main buildings, which have undergone several partial renovations over the years. However, an energy analysis has highlighted a pressing need for further upgrades, as substantial heat loss continues to occur through the building envelope, particularly the roof and existing energy systems are outdated.

Utilizing BIM to develop a detailed model of the Amaldi-Sraffa complex in Revit allows for detailed energy analysis based on the structure's embedded material and thermal characteristics. This approach enables an accurate assessment of the building's current energy performance. Moreover, BIM supports the evaluation of multiple energy efficiency strategies, particularly for enhancing insulation. By simulating and analyzing various improvement scenarios, more sustainable solutions will be identified and applied, optimizing the complex's energy use, and improving existing conditions. Additionally, conducting on-site visits to accurately assess the current condition of the school before creating an as-built model will be implemented.

Establishing a detailed as-built model of the building's current conditions is crucial for ensuring accuracy and reliability, as this model will provide a baseline for assessing various energy efficiency strategies. Once the BIM as-built model for the Amaldi Sraffa Complex has been developed, Edilclima software will be employed to conduct energy efficiency calculations in line with Italian regulations and standards.

For the detailed analysis in the Edilclima application, only one building from the complex will be considered: Building 3 L.S. Amaldi. Unlike other buildings in the complex, it has not undergone any improvement projects in recent years and needs retrofitting.

There are several reasons that Edilclima application has been chosen for the energy efficiency calculations. The first one being, unlike other applications like Docet, which has a limitation of 200 square meters, Edilclima does not impose any size constraints, making it highly adaptable to different project scales without restrictions on the size of the building. Edilclima ensures full compliance with both the national UNI/TS 11300 law and the Piemonte regional laws, which is essential for the case study located in the Piemonte region. This dual compliance guarantees that the software meets both national and local regulations for energy performance certification. Also offers comprehensive economic evaluation features, including the ability to compare different projects' payback periods. This is crucial for assessing the cost-effectiveness of energy-efficient solutions in the case study, making it possible to perform in-depth financial analyses. Since the case study is developed in a BIM (Building Information Modeling) environment, Edilclima's compatibility with BIM is a significant advantage. This integration allows for seamless workflows, supporting the design and analysis of energy performance within the BIM model.

Using the BIM and Edilclima models, different approaches to enhance the complex's energy performance will be evaluated, considering both economic viability and sustainability. The proposed design strategies will be divided into two categories. The first focuses on reducing energy consumption in the Amaldi Sraffa high school building. In this category, one approach involves the integration of solar panels into the existing structure, while another proposes replacing the current condensing boilers with more efficient models.

The second category focuses on insulation strategies, with three approaches being evaluated: enhancing the green roof, insulating the existing roof with EPS, and implementing insulation using Wood Fiber Panels (WFP). Each approach will be assessed for its potential to improve energy efficiency, considering both economic feasibility and sustainability.

In the economic analysis, key factors include regulatory and standard compliance, available incentives, payback period, initial cost, maintenance costs, and annual energy savings (kWh/m^2). For the sustainability analysis, criteria such as the use of sustainable materials, compliance with the CAM Decree's sustainability standards, lifespan, recyclability, and annual CO_2 reduction (kg) will be considered. These metrics will provide a thorough evaluation of each approach's viability and long-term benefits for energy efficiency improvements in the Amaldi-Sraffa complex.

4. CASE STUDY ANALYSIS OF SCHOOL COMPLEX AMALDI IN ORBASSANO

4.1 Territorial And Urban Planning Framework

Orbassano is a municipality located in the Piedmont region of northern Italy, specifically within the Metropolitan City of Turin. lies approximately fifteen kilometers southwest of Turin, the capital of the region. It is situated in the Po Valley and is surrounded by various other towns and municipalities. As of recent estimates, the population is around 23,000 residents. The surrounding region features a mix of urban and rural landscapes with various sectors represented, including manufacturing and services. (Orbassano, n.d.)

The Amaldi School's complex area is 55,400 square meters and is located in the southwestern part of the city of Orbassano, in the province of Turin. With Strada Volvera and Via dei Fraschei to the east, Via Fratelli Rosselli to the west, Via Sacco e Vanzetti to the north, and Via dei Fraschei to the south, the study area is shaped like a polygonal shape. The complex consists of three high school buildings and their gyms as well as the external spaces for sports such as running track and basketball field. The school complex is in a largely residential neighborhood, south of the complex consists of farmlands while other facades have more residential buildings. Near the complex there are other educational areas such as "La Gabbianella" Day Care Center and "Anna Frank" Primary School. Buildings have some distance from each other therefore this feature allows natural ventilation and solar rays to arrive to classrooms especially for the south facades of the existing three buildings. Schools in the project area have facades in the direction of southwest. Also, in the area there are basketball courts and running tracks oriented north-west to south-east. (I.I.S. Amaldi Sraffa, 2024)

Figure 17 Top view of the site. Google (2024) Orbassano

4.1.1 The school

The I.I.S. "Amaldi-Sraffa" was created in September 2014 following the merger of two institutions, I.I.S. "Edoardo Amaldi" and I.I.S. "Piero Sraffa." It consists of three buildings that offer a variety of academic programs, including a Technological Technical Institute, both Traditional and Applied Science High Schools, a Language High School, a Humanities High School, and an Economic Technical Institute, which also provides an evening course in "Administration, Finance, and Marketing." Additionally, the school complex features three gymnasiums. The school currently operates sixty-eight classes, with an average of twenty-one students per class, totaling 1,371 students and 181 teachers. The regular class hours are from 8:10 a.m. to 4:10 p.m., except on certain Tuesdays when classes end earlier at 3:20 p.m. (I.I.S. Amaldi Sraffa, 2024).

To broaden its reach and enhance its educational offerings, the institute has introduced a range of afternoon programs over the years. These projects involve not only its own students but also collaborations with universities and international partners. They include inclusive events, STEAM projects aimed at promoting sustainability, as well as afternoon language and math courses. In the 2023/2024 school year, the institute introduced a new study track, "Chemistry, Materials, and Biotechnology," within the Technical Technological Institute. Analysis shows a notable 33.3% increase in enrolment for technical institutes, particularly in business and technology courses, compared to the 2022/2023 school year. (*I.I.S. Amaldi Sraffa*, 2024)

Figure 18 Entrance of Higher Education Institute Amaldi SRAFFA

4.1.2 Building's Structure

The "Amaldi-Sraffa" school complex comprises three building blocks that were constructed beginning in the 1970s that consists of classrooms and offices, and gyms, which also includes spaces for laboratories and services below. The three buildings are situated within a shared green space, creating a campus-like environment. They offer significant potential for development, and the number of classes they accommodate is increasing. Each building includes a B1 type gym. The outdoor areas adjacent to the gym are currently unused, as they require new flooring and associated sub-bases. The gym itself is an independent structural unit that is utilized by external sports clubs due to its size and the availability of separate access. The load-bearing system features a mix of partitions, reinforced concrete pillars, and a steel frame, topped with a roof made of metal lattice beams (Orbassano - I.I.S. Amaldi-Sraffa, Via Rosselli 35 - Riqualificazione infrastrutture sportive , n.d.)

Several renovation projects have been undertaken in the past, but they only addressed certain areas of the building complex. The most recent renovation for the Amaldi-Sraffa gym involved replacing the external window frames. Although the changing rooms are outdated, they are not a priority for immediate repairs and can be upgraded with basic maintenance. A seismic vulnerability assessment has identified several weaknesses in comparison to current construction standards, particularly at the beam-pillar joints, the perimeter beams, and the components of the metal roof truss. Additionally, an energy analysis has revealed an urgent need for energy efficiency upgrades due to significant heat loss through the building's envelope. (Palestre e auditorium del complesso Amaldi – Sraffa: aggiornamento, 2024)

4.1.3 Mobility

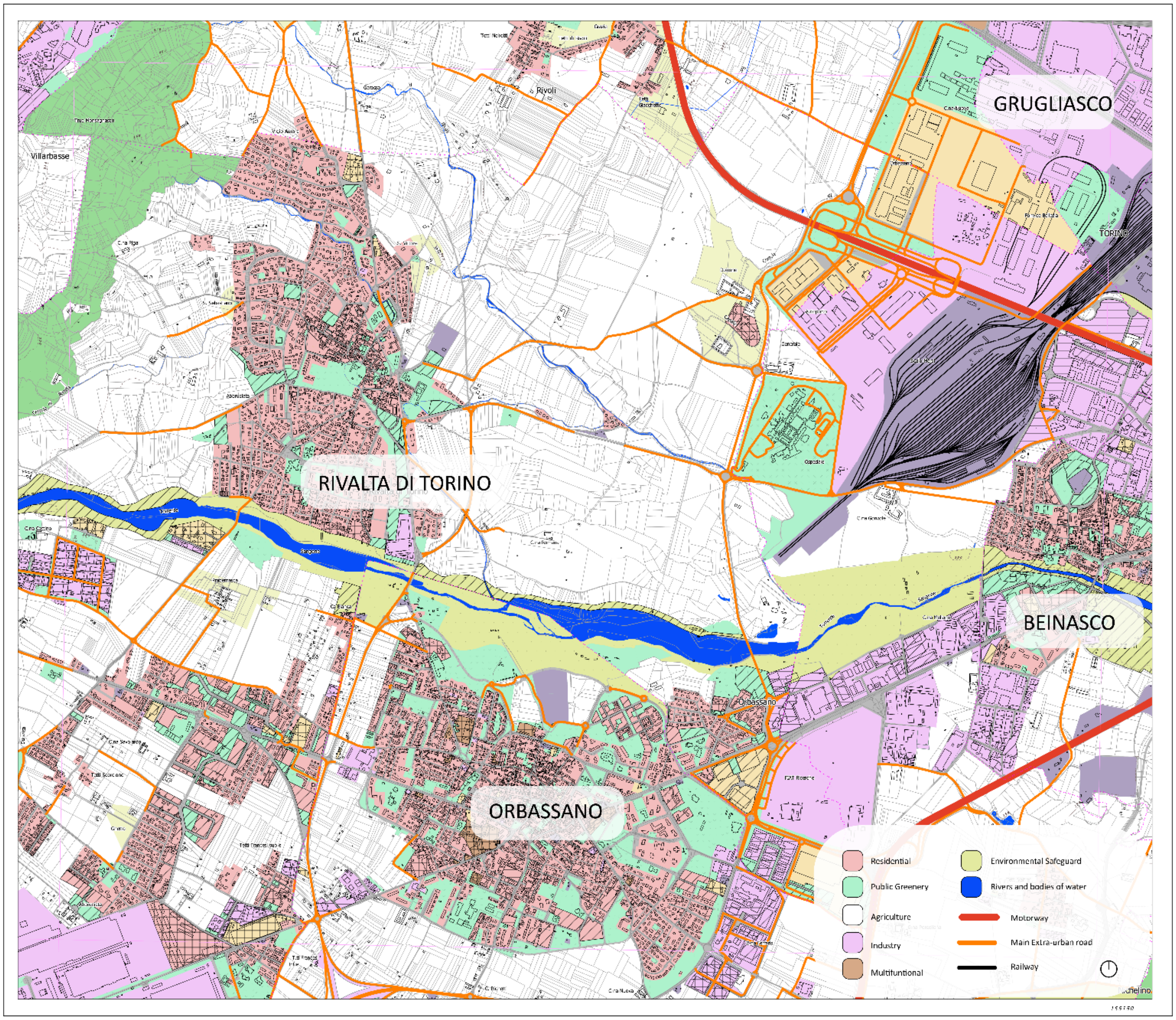


Figure 19 Mobility and connecting hubs. Made with QGIS

IIS Amaldi-Sraffa not only includes students from the Orbassano but also there are number of students from nearby towns such as Beinasco, Rivalta di Torino, Bruino, Piossasco and Volvera. There are some bus routes from these nearby towns for high schools' students to use to reach to the high school complex. (*I.I.S. Amaldi Sraffa*, 2024)

The figure above shows a regional transportation network focused around Orbassano and its surrounding areas and focal points. It is also possible to see road networks. Motorways connect major urban areas, facilitating high-speed travel between towns. Urban Arterial Roads and Extra-Urban Primary Roads represent the main routes connecting towns and cities, used for intercity travel. Extra-Urban Secondary Roads show less prominent, but still important, routes that link smaller towns and residential areas. Railways indicate the train routes in the region, connecting towns like Torino and the surrounding areas.

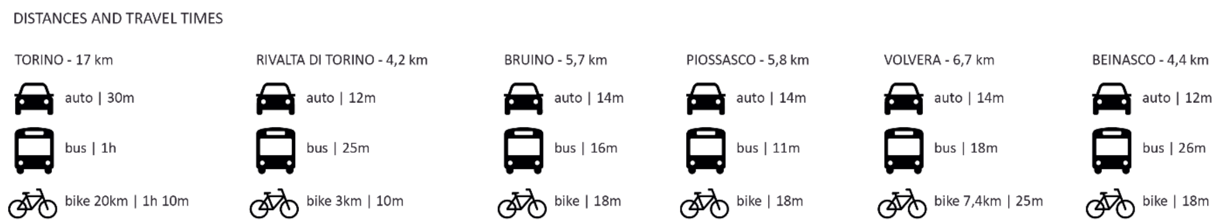


Figure 20 Mobility and distances made with Google Maps

The figure above illustrates the distances between the school complex in Orbassano and key central locations, showing the estimated travel times depending on various modes of transportation.

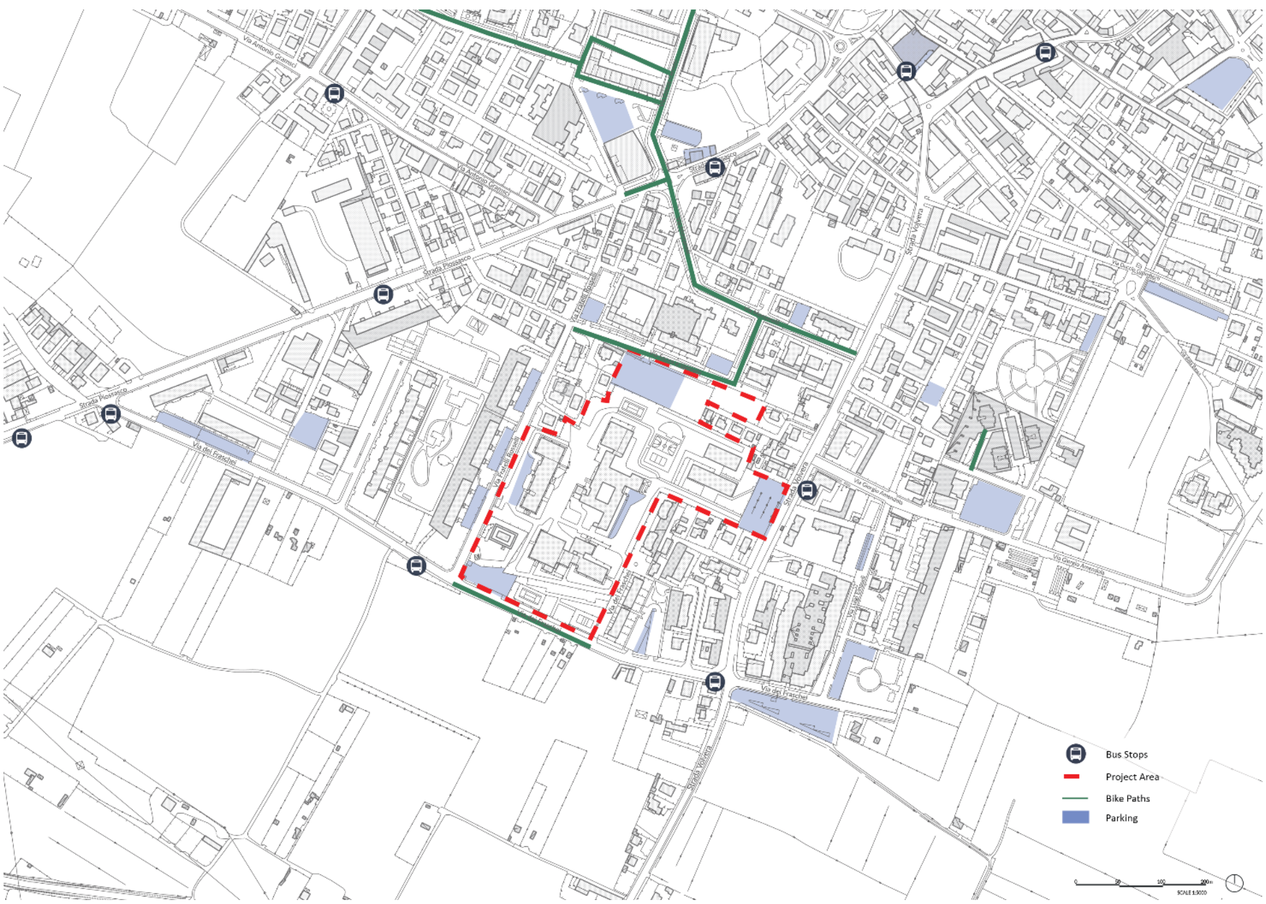


Figure 21 Mobility Made with QGIS

The figure 20, reveals the availability of public parking lots in the area, including designated spaces for disabled parking. While there are some bike lanes, such as those on Via Montanelli, it is evident that these paths are not continuous and are confined to a limited area. The nearest bus stops for local travel are located on Via dei Fraschei and Strada Volvera, from which it is possible to reach the city center of Orbassano. For those traveling to nearby towns or the center of Torino, the closest bus stop is situated on Strada Piossasco, approximately 400 meters from the school complex.

4.1.4 Intended Use

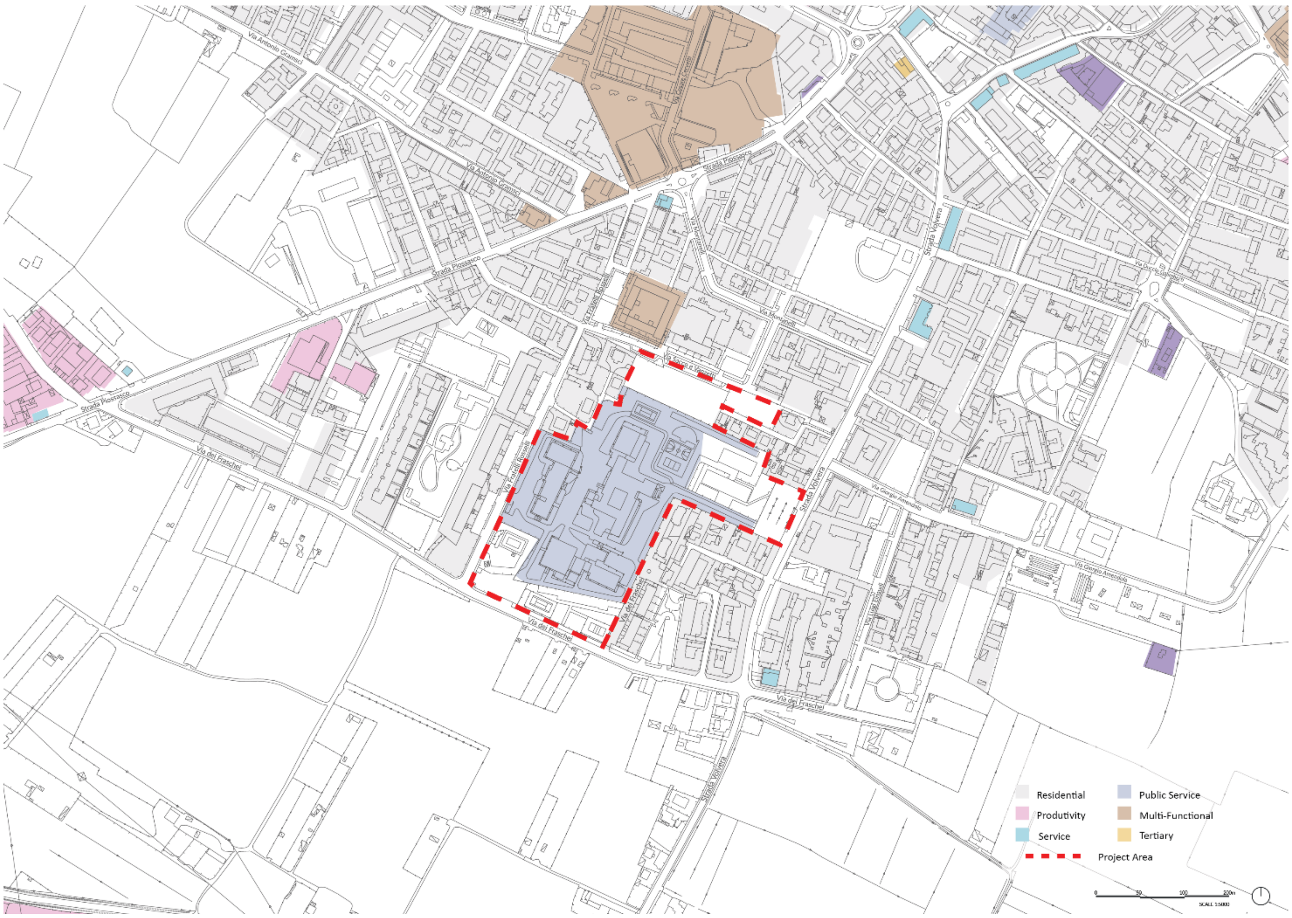


Figure 22 Intended Use Made with QGIS

As can be seen from the figure above, the complex appears to be in an area that is primarily residential. Additionally, there are some business and service locations close by within walking distance. Supermarkets are on the complex's northern side. There are a few locations for productive facilities in the southwest. Farmlands dominate the west side of the Via dei Fraschei.

4.1.5 Adjacent Activities

The school complex is adjacent to the “La Gabbianella” Day Care Center to the south and the "Anna Frank" Primary School to the east. “La Gabbianella” provides care services for individuals with mild to moderate intellectual and physical disabilities, accommodating up to thirty users daily. Its service area includes Beinasco, Rivalta, Bruino, Piossasco, and Volvera, both in terms of those receiving care and the staff. The "Anna Frank" Primary School is part of the "Orbassano1" Comprehensive Institute, with ten classes averaging 20 students per class and a teaching staff of 20. (I.I.S. Amaldi Sraffa, 2024)

4.2 Bioclimatic Framework

4.2.1 Path of the Sun and Wind

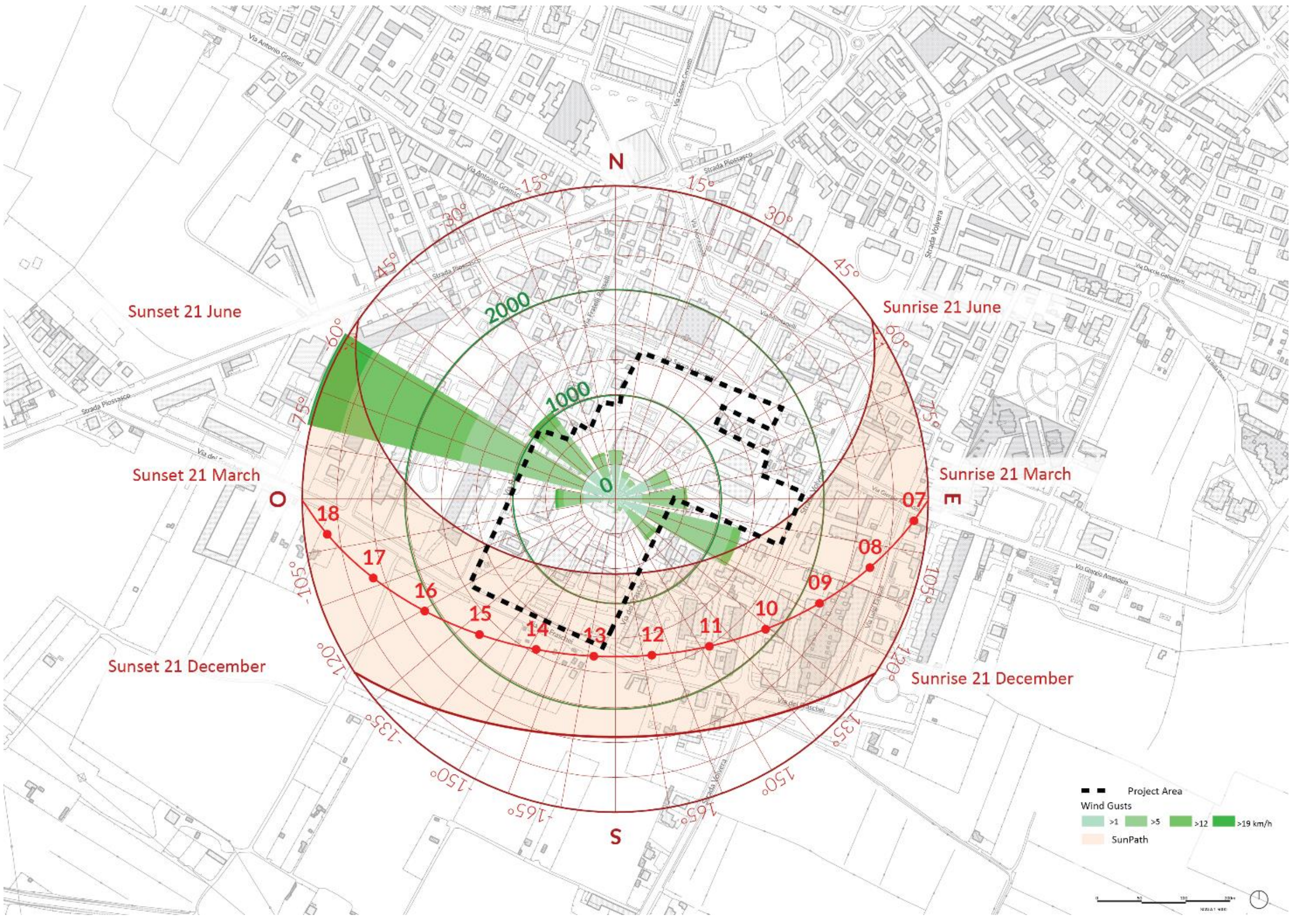


Figure 23 Sun and wind diagram of the Orbassano made with (3D Sun-Path, n.d.) and (Orbassano, n.d.).

It can be seen in figure 22, the sun's path during different seasons. Information regarding the hours that students attend the school can be extracted from the graph. This chart has a circle for every 15 degrees of altitude. During the winter months the sun's altitude is lower.

Figure on top shows the medium of wind gusts. It can be seen that the major direction of the wind is north-west with the maximum amount of speed calculated 19 km /h. Also winds from the south-east with 12km/h are recorded.

4.2.2 Shadow Analysis

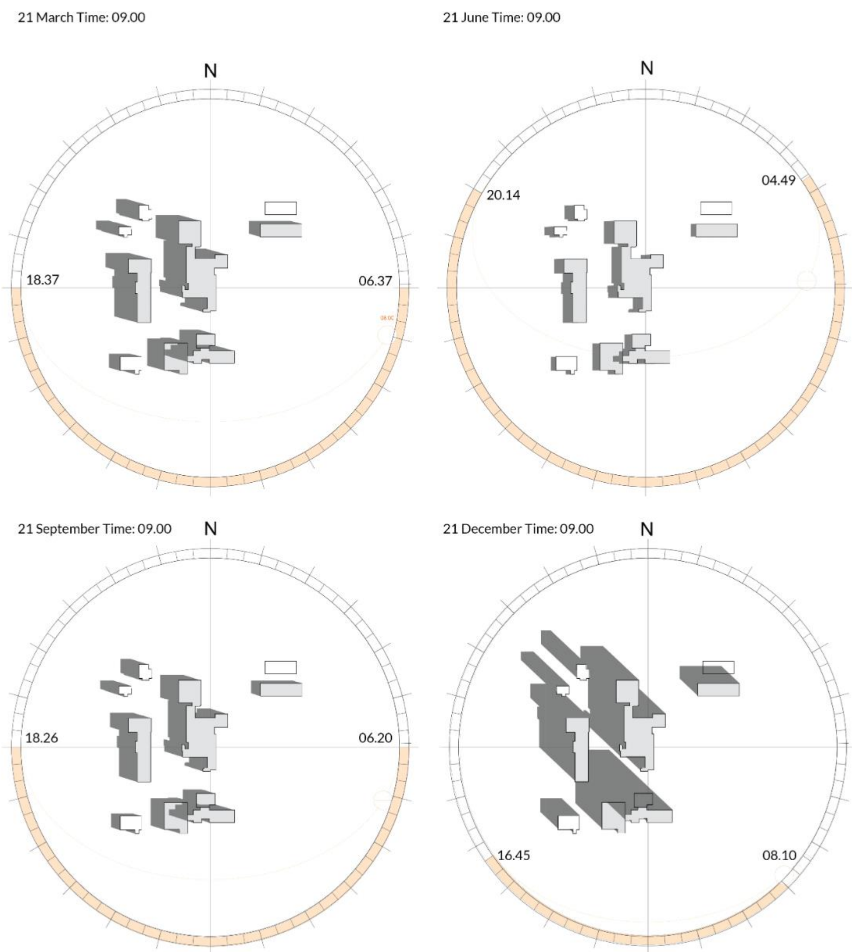


Figure 24 Shadow Analysis made with Revit Solar Study

From the shadow analysis, the duration of sun exposure and the times of sunrise and sunset can be observed for the equinoxes on March 21 and September 21, as well as for the solstices on June 21 and December 21 for school buildings. While 21 June is the longest day with almost 12 hours of daylight, 21 December is the shortest with 8 hours of sunlight.

4.2.3 Precipitation

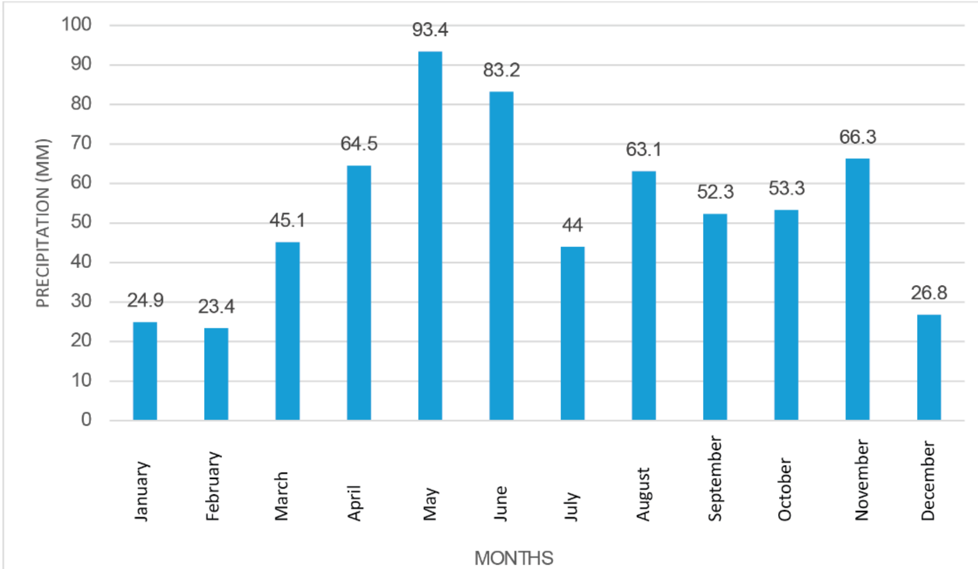


Table 3 Average monthly precipitation in Orbassano and monthly precipitation days. A.R.P.A. station. (Stazione: BAUDUCCHI, n.d.)

The graph illustrates the average monthly precipitation values derived from Bauducchi A.R.P.A Station's daily measurements, using historical data up to December 31, 2023. It indicates that, on average, the months with the highest precipitation are May, June, and November, while December, January, and February are the months with the least rainfall.

Based on the daily precipitation data, an analysis was conducted on peak events characterized by continuous and heavy rainfall. The highest recorded amount of precipitation over a three-day period was 155.6 mm, which occurred from February 14 to 17. Additionally, another notable peak event took place when a total of 142.2 mm of rain fell over three days starting on November 22.

4.2.4 Temperature

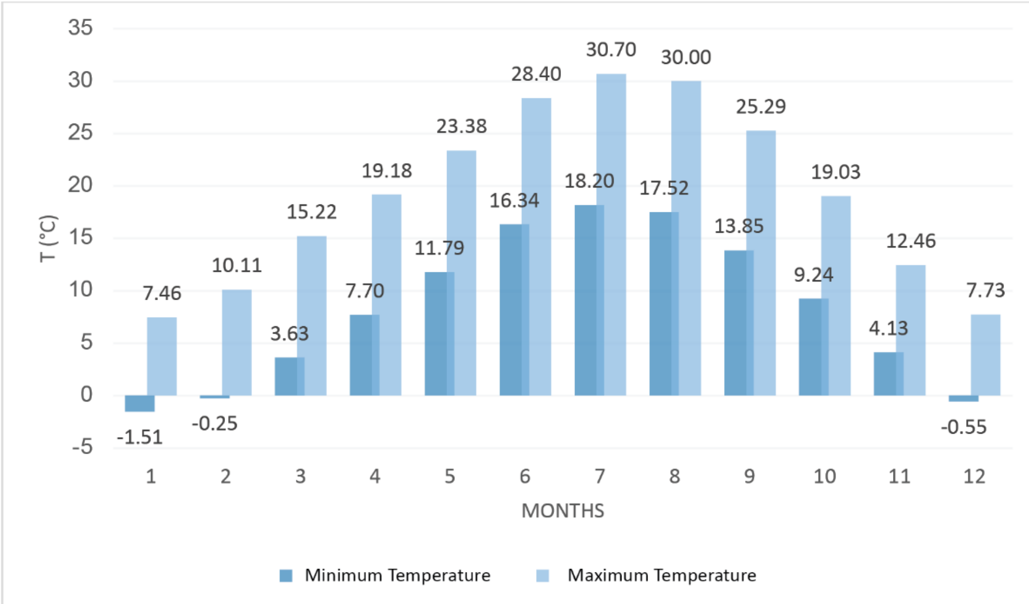


Table 4 Monthly averages of the maximum temperature obtained from A.R.P.A. station's data in Turin Vallere.

Data from A.R.P.A shows that maximum monthly averages of temperature in Orbassano measured in July at 30.7 °c and minimum monthly averages of temperature is in January at -1.51 °c.

4.2.5 Solar Radiation

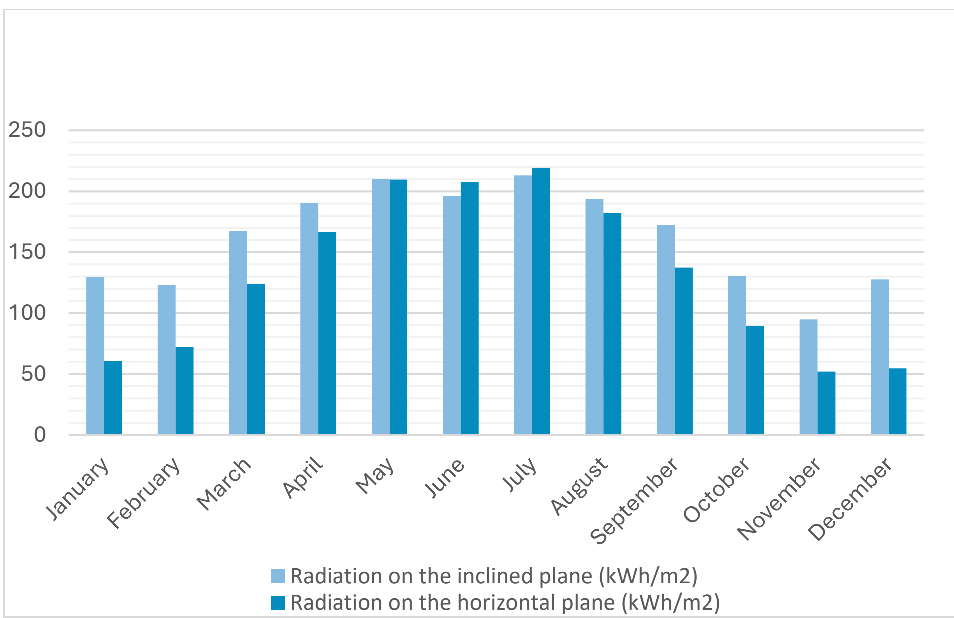


Table 5 Monthly averages of solar radiation (expressed in kWh/m2 month). Values processed from data from (JRC Photovoltaic Geographical Information System (PVGIS), 2016)

To estimate the potential solar energy production, it is essential to assess the solar radiation reaching the specific location, which is situated at a latitude of 45.001 and a longitude of 7.531.

Monthly averages of solar radiation are the maximum in the month of July with 219.4 (kWh/m2) and the least is in November with 51.89 (kWh/m2). (JRC Photovoltaic Geographical Information System (PVGIS), 2016)

4.3 Energy Assessments of The Buildings

Figure 25 Area of the school complex under review with identification of the three buildings codes (source: Energy Diagnosis of 6-12- 2017, L1-007-017_019_021)

Energy diagnostic analysis of the buildings within the school complex, as detailed in the technical documents, has been conducted within the location and identification of the three primary buildings are illustrated in Fig. 24. Information regarding energy assessment of three buildings is provided.

Firstly, the analyzed complex is situated in an area with a Growing Degree Days (GDD) value of 2617, placing it within the climate zone E classification, which encompasses values ranging from 2101 to 3000.

4.3.1 Building 1 (L1-007_017) - "I.T.C. SRAFFA"

At the table below it is possible to see information of building 1 I.T.C. Sraffa's regarding energy assessments with external surface area, net volume and heated and cooled areas and volumes. Information regarding the building is collected from the energy certificate of the building. (Certificazione energetica APE)

Gross external surface area (m^2)	9.975,68
Useful heated surface (m^2)	8.586,02
Useful cooled surface area (m^2)	148,89
Net volume (m^3)	27.639,46
Gross heated volume (m^3)	33.751,13
Gross volume cooled (m^3)	566,66
Gross roof surface area (m^2)	3.350

Table 6 Building 1 (L1-007_017) - "I.T.C. SRAFFA"

Table 7 Energy Services Available for Building 1 (L1-007_017) - "I.T.C. SRAFFA"

The table above indicates that in building one winter and summer air conditioning and mechanical ventilation exist. As well as domestic hot water production and lighting features.

In 2017, the building was classified as energy class C, with a total non-renewable energy performance index (EPgl, nren) of 257.81 kWh/m^2·a. The energy sources utilized include:

- Electricity
- Natural gas

4.3.2 Building 2 (L1-007_019) - "I.T.I.S. AMALDI"

At the table below it is possible to see information Building 2 I.T.I.S. Amaldi's regarding energy assessments with external surface area, net volume and heated and cooled areas and volumes. Information regarding the building is collected from the energy certificate of the building. (Certificazione energetica APE)

Gross external surface area (m^2)	6.286,79
Useful heated surface (m^2)	3.677,18
Useful cooled surface area (m^2)	0
Net volume (m^3)	15.635,60
Gross heated volume (m^3)	18.333,31
Gross volume cooled (m^3)	0
Gross roof surface area (m^2)	1.635

Table 8 Building 2 (L1-007_019) - "I.T.I.S. AMALDI

Table 9 Energy Services Available for Building 2 (L1-007_019) - "I.T.I.S. AMALDI

The table above indicates that in building two there is winter air conditioning but not summer air conditioning and mechanical ventilation exist. As well as domestic hot water production and lighting features.

In 2017, the energy class of I.T.I.S. Amaldi was C, and the overall non-renewable energy performance index ($EP_{gl, nren}$) was 339.03 kWh/m^2·a.

The energy sources used are:

- Electricity
- Natural gas

4.3.3 Building 3 (L1-007_021) – "L.S. "AMALDI"

At the table below it is possible to see information Building 3 L.S. Amaldi's regarding energy assessments with external surface area, net volume and heated and cooled areas and volumes. Information regarding the building is collected from the energy certificate of the building. (Certificazione energetica APE)

Gross external surface area (m^2)	7.730,35
Useful heated surface (m^2)	4.437,72
Useful cooled surface area (m^2)	522,89
Net volume (m^3)	18.458,16
Gross heated volume (m^3)	22.053,29
Gross volume cooled (m^3)	1.874,1
Gross roof surface area (m^2)	2.040

Table 10 Building 3 (L1-007_021) – "L.S. "AMALDI"

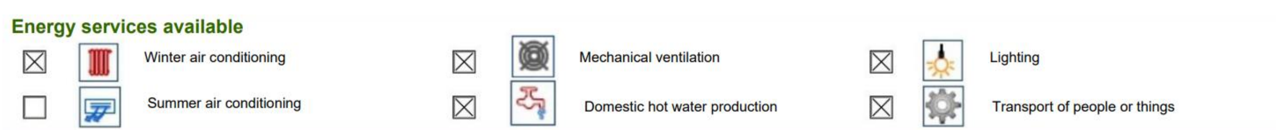


Table 11 Energy Services Available for Building 3 (L1-007_021) – "L.S. "AMALDI"

The table above indicates that in building two there is winter air conditioning but not summer air conditioning and mechanical ventilation exist. As well as domestic hot water production and lighting features.

In 2017, the energy class of L.S. Amaldi was C, and the overall non-renewable energy performance index ($EP_{gl, nren}$) was 272.17 kWh/m^2·a.

The energy sources used are:

- Electricity
- Natural gas

4.3.4 Total Electricity Consumption

Months	F1 [kWh/month]	F2 [kWh/month]	F3 [kWh/month]
January	18 752	6 420	10 023
February	17 243	5 578	7 872
March	16 914	5 755	7 957
April	11 163	4 430	8 239
May	13 315	4 044	6 271
June	7 950	2 888	4 935
July	5 095	2 647	4 915
August	4 235	2 464	4 969
September	9 669	3 330	4 887
October	14 955	4 164	5 900
November	18 689	6 233	9 064
December	16177	6251	11706
kWh/year	154 157	54 204	86 738
Total kWh/year	295.099		

Table 12 Total Electricity Consumption

Data from the electricity bills of the school complex are indicated on the table shown above to calculate cumulative energy consumption. At the year 2023 Total kWh of electricity consumption was 295.099 kWh.

4.4 Swot Analysis

Based on the project details for the area surrounding the "Amaldi-Sraffa" school complex in Orbassano, here is the SWOT analysis:

Strengths

Strategic Location: The school complex is located in a predominantly residential area, making it easily accessible to students from nearby towns such as Beinasco, Rivalta di Torino, Bruino, Piossasco, and Volvera via public transportation and partial bicycle routes.

Large Green Spaces: The area is well-designed with buildings positioned to maximize solar energy in winter and natural cross-ventilation, with ample green spaces, providing a comfortable environment.

Existing Infrastructure: Facilities like gyms and classrooms are already present, which can be further enhanced for energy efficiency and structural improvements.

Weaknesses

Aging Infrastructure: The buildings, constructed in the 1970s, have been identified as having seismic vulnerabilities and significant energy inefficiencies, requiring updates to the building envelope to reduce heat loss.

Limited Bicycle Paths: Although some bike paths exist, they are not continuous, limiting accessibility for students and staff who may want to commute by bicycle.

Disconnection from Major Transit Hubs: The nearest bus stop with connections to the center of Torino is 400 meters away, which might be less convenient for some students.

Opportunities

Sustainability Projects: The project area can be more developed with sustainable initiatives like enhancing the existing green spaces and improving the biodiversity of the area.

Energy Efficiency Improvements: Significant opportunities exist for energy retrofits, including installing better insulation, improving the window structures, and considering renewable energy sources.

Community Integration: The school complex could integrate more with surrounding facilities, such as the "La Gabbianella" Day Care Center and "Anna Frank" Primary School, to promote educational and community events.

Threats

Financial Constraints: Structural and energy improvements are costly, and there may be limitations on available funding, especially for large-scale upgrades.

Seismic Risk: The area has some seismic vulnerabilities in its current infrastructure, posing a potential risk if not addressed in a timely manner.

Regulatory and Compliance Delays: Regulatory processes, such as obtaining or renewing necessary certifications (e.g., fire prevention certificates for gym usage), could delay infrastructure improvements.

This SWOT analysis highlights the potential for growth and the existing challenges in improving the school complex in Orbassano.

4.5 Evaluation of the Case Study

The sections above give information regarding the I.I.S. "Amaldi-Sraffa" school complex in order to provide thorough understanding of the context with breakdown of the urban and territorial planning framework within its surrounding environment in Orbassano. Gives a foundation for addressing how these external factors influence energy consumption, transportation, and sustainable development strategies that could help with later impact of energy efficiency strategies.

Descriptions of the building's structural elements, such as the load-bearing systems and material composition are also mentioned as well as previous renovation efforts, such as window replacements in the gymnasium. Although these interventions have partly improved the building's composition it is not possible to mention long-term sustainable interventions.

Information regarding climatic data such as solar paths, wind patterns, and precipitation can be utilized for evaluating feasibility of different energy efficiency strategies. As well as the data regarding classification of buildings and detailed energy consumption figures could significantly benefit from an evaluation regarding alternative energy sources and strategies.

Lastly, the SWOT analysis provides an overview of the strengths and weaknesses of the I.I.S. "Amaldi-Sraffa" school complex. To achieve successful outcomes in this case study, it is essential to address the weaknesses while capitalizing on the site's strengths.

5. MODELLING THE EXISTING SCHOOL COMPLEX USING BIM

Following the analysis and research conducted on the I.I.S. Amaldi-Sraffa project, it was determined to use it as a case study to propose various enhancements. Prior to implementing these improvements, the existing structure of the Amaldi-Sraffa school complex should be modeled using Revit BIM. This modeling should achieve the highest possible level of detail, utilizing the available documentation.

Figure 26 Conducted site inspections and updated models in Revit based on inspection results.

After conducting the analysis, point clouds captured by drones were utilized to model the external surfaces of the I.I.S. Amaldi-Sraffa school complex using Autodesk Recap. This initial step is for accurately representing the existing conditions of the school buildings before beginning the detailed modelling process in Revit. The focus will be on the three high school complexes and exterior surroundings, ensuring that the new design approaches integrate seamlessly with the current architectural features. This approach leverages advanced technology for precise data collection and modelling.

The point cloud feature in Autodesk Revit allows users to import and work with 3D point cloud data, typically gathered from laser scans. This functionality aids in creating accurate 3D models of existing structures, which can be used for renovation, retrofitting, or analysis. Users can manipulate the point cloud data to help in the modelling process, ensuring that new designs integrate seamlessly with existing conditions. (Product Documentation, n.d.)

Figure 27 importing 3d point cloud data to Revit BIM Software

To create the most accurate models in Revit, it is essential to integrate existing point cloud data, 2D CAD drawings, and site visits. The levels of the buildings are verified—often double or triple-checked—to ensure precision. Accurate levels are established within Revit, providing a reliable foundation for design development. Additionally, with the ability to import CAD files into Revit, designers can cross-reference these drawings to check for accuracy, further enhancing the fidelity of the model through comprehensive data validation.

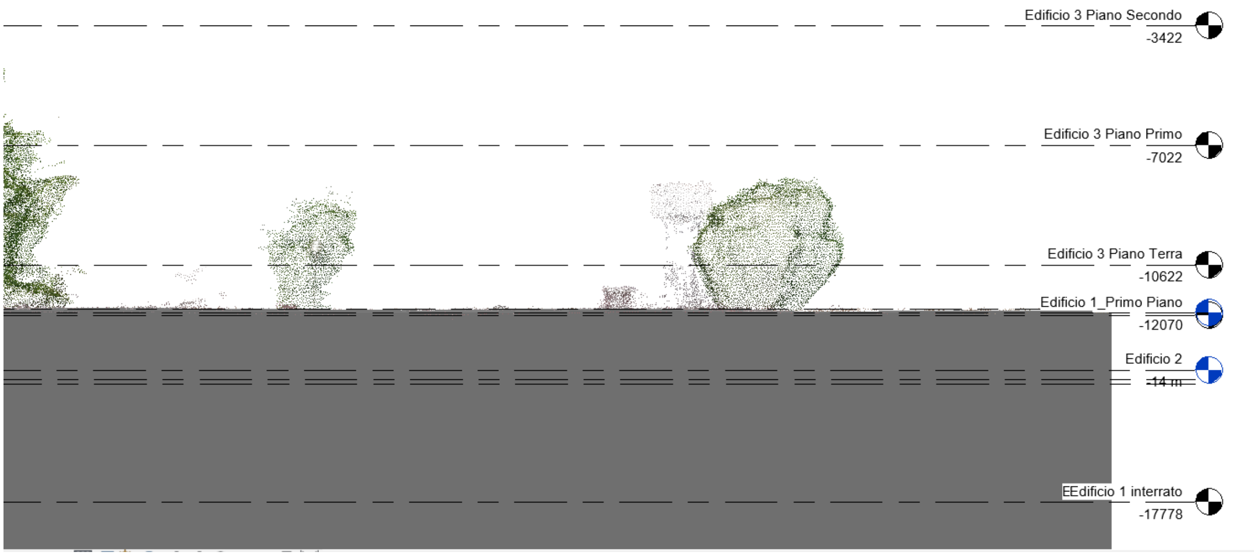


Figure 28 Adding information regarding levels according to point cloud information.

Reference levels are established to facilitate the association of parameters, such as the heights of columns and walls. This is crucial for ensuring that every component added to the model—whether a window, piece of furniture, or system—relates accurately to a reference plane.

After establishing the reference levels, the next crucial step is to create views for the buildings. This process is essential as it provides accurate information related to the project, facilitating better communication among stakeholders and enhancing the overall understanding of the design. These views allow for a thorough visualization of the project's various components, ensuring that all aspects are correctly represented and accessible for review and analysis.

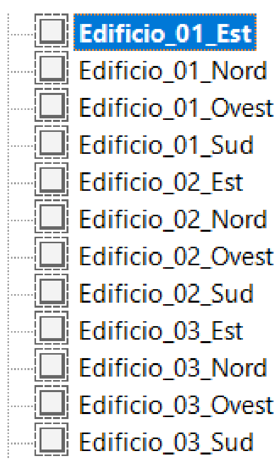


Figure 29 Screenshot from Revit's Project Browser Showing different elevation views for the Amaldi Sraffa Complex

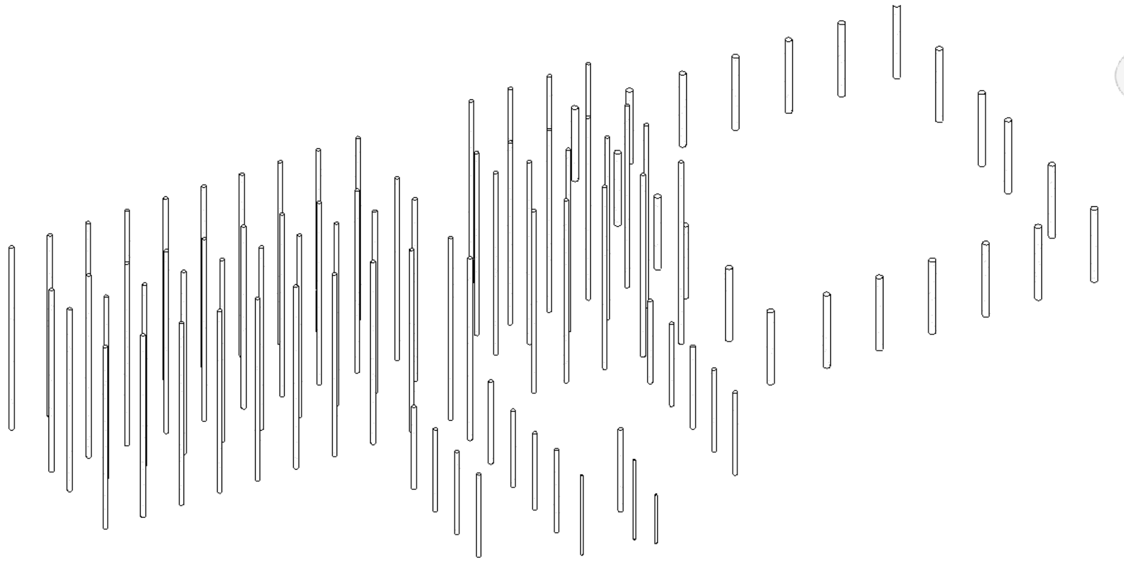


Figure 30 Modelling Existing Columns for Building 3

Figure 30 illustrates the modeling of one of the buildings within the existing structure. This process has also been applied to all three buildings, ensuring a correct representation of the entire complex.

Utilizing the existing point clouds and CAD drawings, the modeling process begins by incorporating structural information for the buildings. This step ensures that the model accurately reflects the essential structural elements, setting the stage for detailing and integration of additional systems. By focusing on structural data first, the model can effectively support subsequent design considerations and enhancements.

Using the documents detailing at the 'Thermal and hygrometric characteristics of the opaque components of the envelope' (according to Ministerial Decree 13.12.93-Table 1 and UNI 10344), it is possible to determine the structure types and thermal values, such as thermal resistance and transmittance. This information, which applies to external elements like walls, roofs, and basements, is integrated into the model to ensure the thermal performance of the building envelope is accurately represented.

CARATTERISTICHE TERMICHE E IGROMETRICHE DEI COMPONENTI OPACHI DELL' INVOLUCRO

secondo D.M. 13.12.93 -Tabella 1 e UNI 10344

Tipo struttura: M1_PARETE ESTERNA — Codice struttura M23

Nr.	Descrizione	s (m)	λ (W/mK)	C (W/m²K)	ρ (kg/m³)	δα (10⁻¹²kg/msPa)	δυ (10⁻¹²kg/msPa)	R (m²K/W)
1	Intonaco di calce e gesso	0,01500	0,700	46,667	1400	17.545	17.545	0,02143
2	Muratura in laterizio pareti interne (um. 0.5%)	0,24000	0,250	1,042	600	27.571	27.571	0,96000
3	Intercapedine d'aria	0,19500	0,220	1,128	1	193	193	0,88636
4	Calcestruzzo per parete prefabbricata	0,20000	1,670	8,350	1800	3.86	3.86	0,11976

Conduttanza unitaria superficiale interna: 7,700

Conduttanza unitaria superficiale esterna: 25,000

Resistenza unitaria superficiale interna: 0,130

Resistenza unitaria superficiale esterna: 0,040

SPESSORE TOTALE (m): **0,650**

TRASMITTANZA TOTALE (W/m²K): **0,464**

RESISTENZA TERMICA TOTALE (m²K/W): **2,157**

Simbologia:
- s spessore dello strato
- C conduttanza unitaria
- δα permeabilità al vapore nell' intervallo di umidità relativa 0 - 50 %
- R resistenza termica dei singoli strati
- λ conduttività termica del materiale
- ρ massa volumica
- δυ permeabilità al vapore nell' intervallo di umidità relativa 50 - 95 %

Figure 31 A page from the document the 'Thermal and hygrometric characteristics of the opaque components of the envelope' for existing walls.

Family: Basic Wall
Type: M11
Total thickness: 370.0 (Default)
Resistance (R): 0.6497 (m²·K)/W
Thermal Mass: 471.33 kJ/(m²·K)
Sample Height: 6000.0

Layers — EXTERIOR SIDE

	Function	Material	Thickness	Wraps	Structural Material	Variable
1	**Core Boundary**	**Layers Above Wrap**	**0.0**			
2	Finish 1 [4]	Edificio_02_Intonaco di calce e gesso	15.0	☐	☐	☐
3	Structure [1]	Muratura in laterizio pareti esterne	180.0	☐	☑	☐
4	Thermal/Air Layer [3]	Intercapedine d'aria	85.0	☐	☐	☐
5	Structure [1]	C.l.s. Per Pareti Esterne	90.0	☐	☐	☐
6	**Core Boundary**	**Layers Below Wrap**	**0.0**			

Figure 32 Updating Wall types on Revit.

Figure 32 demonstrates how, based on the information gathered from the documents, Revit families and types were updated with names corresponding to the specific structural and thermal characteristics. This ensures that the model is accurately aligned with the documented data, allowing for precise identification of building elements such as walls, roofs, and basements, including their thermal performance attributes.

CARATTERISTICHE TERMICHE E IGROMETRICHE
DEI COMPONENTI OPACHI DELL' INVOLUCRO
secondo D.M. 13.12.93 -Tabella 1 e UNI 10344

Tipo struttura: P3-1,70X2,88 PORTA IN ALLUMINIO — Codice struttura M1

Nr.	Descrizione	s (m)	λ (W/mK)	C (W/m²K)	ρ (kg/m³)	δα (10⁻¹²kg/msPa)	δυ (10⁻¹²kg/msPa)	R (m²K/W)
1	Alluminio	0,00200	220,0	110000	2700	.0001	.0001	0,00001
2	Intercapedine d'aria verticale 10 mm	0,01000	0,076	7,600	1	193	193	0,13158
3	Alluminio	0,00200	220,0	110000	2700	.0001	.0001	0,00001

Conduttanza unitaria superficiale interna	7,700	Resistenza unitaria superficiale interna	0,130
Conduttanza unitaria superficiale esterna	25,000	Resistenza unitaria superficiale esterna	0,040
SPESSORE TOTALE (m)	**0,014**		
TRASMITTANZA TOTALE (W/m²K)	**3,317**	**RESISTENZA TERMICA TOTALE (m²K/W)**	**0,302**

Simbologia:
- s spessore dello strato
- C conduttanza unitaria
- δα permeabilità al vapore nell' intervallo di umidità relativa 0 - 50 %
- R resistenza termica dei singoli strati
- λ conduttività termica del materiale
- ρ massa volumica
- δυ permeabilità al vapore nell' intervallo di umidità relativa 50 - 95 %

Figure 33 A page from the document the 'Thermal and hygrometric characteristics of the opaque components of the envelope' for existing external doors.

The document on the Thermal and Hygrometric Characteristics of the Opaque Components of the Envelope (per Ministerial Decree 13.12.93-Table 1 and UNI 10344) also contains details about external elements like doors and windows, specifying materials, dimensions, and thermal properties. To ensure the accuracy of this information, it is cross-checked against the point cloud data, confirming the consistency between the documented characteristics and the actual building conditions.

The figure below displays one of the updated families in Revit, revised according to the document that outlines the materials, dimensions, and thermal properties of the building components. These updates ensure that the Revit model accurately reflects the specified characteristics, aligning the virtual design with the real-world data provided in the document.

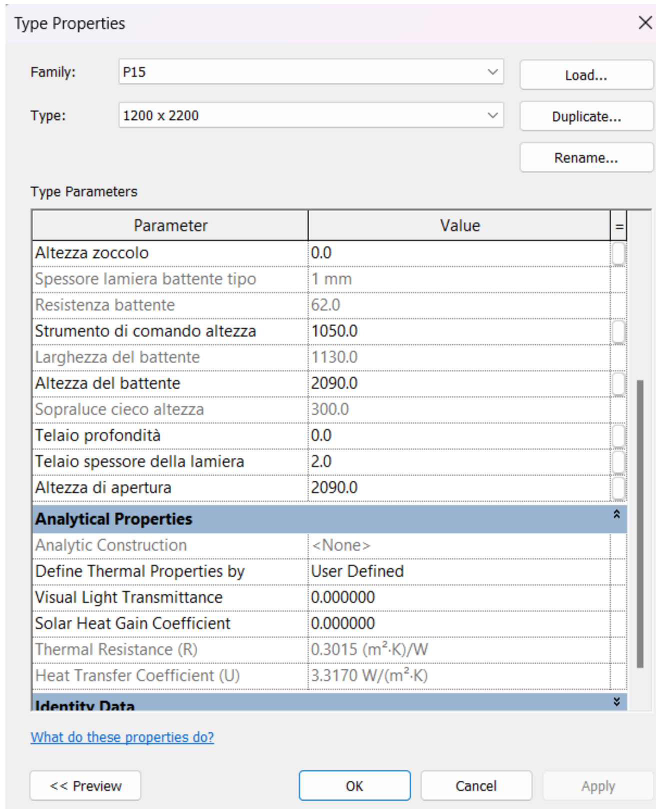


Figure 34 Updating Door families on Revit.

After incorporating all the necessary information regarding walls, windows, and other external elements, the creation of the "as-built" model in Revit was completed. This model accurately represents the current state of the building, reflecting its structural, material, and thermal properties as outlined in the reference documents.

Figure 35 Building 3 North Façade Elevation according to point cloud data.

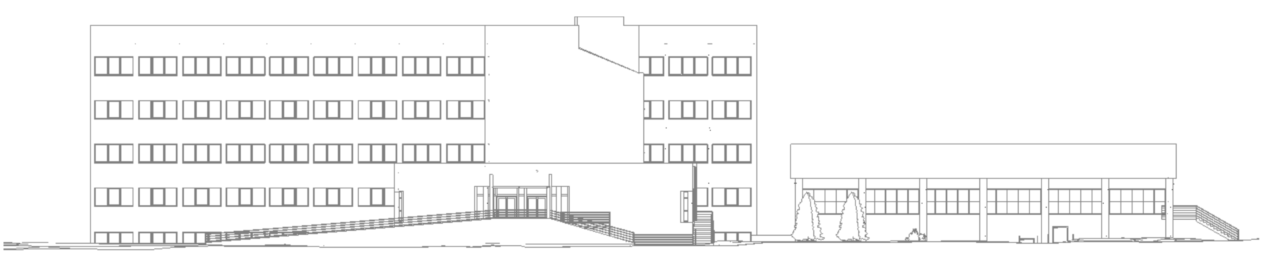


Figure 36 Building 3 North Façade Elevation as- built model

Figure 37 Building 2 West Façade Elevation according to point cloud data.

Figure 38 Building 2 West Façade Elevation as- built model.

After modeling all elements with their structural, material, and thermal properties, Revit enables the creation of detailed schedules for components such as walls, floors, roofs, windows, and doors. These schedules allow for the categorization of information by building, floor level, and element type, while also providing quantities and details about the phase in which each element was created. This capability facilitates precise project management and assessment of material use across different parts of the complex.

Finestre - Caratteristiche Fisiche									
Nome	Dimensioni	Quantità	Descrizione	Costo	Resistenza Termica Totale	Trasmittanza Totale	Solar Heat Gain Coefficient	Fase	Fase di Demolizione
Edificio 1 interrato									
F46	900 x 900	2	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
Edificio 1_auditorium									
F71	1900x1200	33	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$		Stato di Fatto	None
Edificio 1_copertura									
F19	1500x1500	2	Lucernario plexiglass		0.2488 $(m^2\cdot K)/W$	4.0200 $W/(m^2\cdot K)$		Stato di Fatto	None
F20	1000x1000	2	Lucernario plexiglass		0.2488 $(m^2\cdot K)/W$	4.0200 $W/(m^2\cdot K)$		Stato di Fatto	None
F22	1000x1000	1	Lucernario plexiglass		0.2488 $(m^2\cdot K)/W$	4.0200 $W/(m^2\cdot K)$		Stato di Fatto	None
F23	1500x1500	28	Lucernario plexiglass		0.2488 $(m^2\cdot K)/W$	4.0200 $W/(m^2\cdot K)$		Stato di Fatto	None
F24	900x900	1	Lucernario plexiglass		0.2488 $(m^2\cdot K)/W$	4.0200 $W/(m^2\cdot K)$		Stato di Fatto	None
F25	900x900	1	Lucernario plexiglass		0.2488 $(m^2\cdot K)/W$	4.0200 $W/(m^2\cdot K)$		Stato di Fatto	None
Edificio 1_Piano Terra									
F06	3000 x 600	6	Vetro Singolo Serramento Alluminio		0.2083 $(m^2\cdot K)/W$	4.8000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F26	4300 x 1000	5	Vetro Singolo Serramento Alluminio Vetro Singolo Serramento Alluminio Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F27	830 x 500	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$		Stato di Fatto	None
F32	4800 x 2600	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F34	5550 x 2600	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F35	4800 x 2600	2	Vetro Singolo Serramento Alluminio		0.2257 $(m^2\cdot K)/W$	4.4300 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F36	2600 x 1270	2	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F38	1650 x 800	2	Vetro Singolo Serramento Alluminio		0.2083 $(m^2\cdot K)/W$	4.8000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F39	1825 x 915	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$		Stato di Fatto	None
F40	1900 x 1000	3	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F44	6350 x 1000	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F45	2400 x 1650	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F70	100 x 100	135	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$		Stato di Fatto	None
Edificio 1_piano terra									
F01	2350x1500	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F02	3550x1500	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F03	3550x1275	17	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F04	2350x1275	17	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F09	2532x844	3	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F10	3425x844	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F12	3550x510	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F13	2350x950	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F14	15000x900	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F15	560x2645	3	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F16	560x845	2	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F17	465x2360	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F72	1900x550	30	Vetro Doppio Serramento Alluminio		0.3509 $(m^2\cdot K)/W$	2.8500 $W/(m^2\cdot K)$		Stato di Fatto	None
Edificio 1_Primo Piano									
F08	2800 x 600	2	Vetro Singolo Serramento Alluminio		0.2083 $(m^2\cdot K)/W$	4.8000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F27	830 x 500	11	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$		Stato di Fatto	None
F28	4550 x 1500	2	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F29	4550 x 1500	2	Vetro Doppio Serramento Alluminio		0.3509 $(m^2\cdot K)/W$	2.8500 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F30	5550 x 1500	1	Vetro Doppio Serramento Alluminio Vetro Doppio Serramento Alluminio Vetro Doppio Serramento Alluminio		0.3817 $(m^2\cdot K)/W$	2.6200 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F31	4550 x 1500	3	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F32	4800 x 2600	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F33	4800 x 2600	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F37	2600 x 660	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
Edificio 1_secondo piano									
F01	2350x1500	18	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F02	3550x1500	19	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F05	1650x1500	1	Vetro Singolo Serramento Alluminio		0.2711 $(m^2\cdot K)/W$	3.6886 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F09	2532x844	3	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F10	3425x844	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F13	2350x950	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F14	15000x900	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F15	560x2645	2	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F17	465x2360	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F72	1900x550	8	Vetro Doppio Serramento Alluminio		0.3509 $(m^2\cdot K)/W$	2.8500 $W/(m^2\cdot K)$		Stato di Fatto	None
Edificio 2 Piano Interrato									
F07	900 x 900	12	Vetro Singolo Serramento Alluminio		0.2155 $(m^2\cdot K)/W$	4.6400 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F47	1890 x 1500	2	Vetro Doppio Serramento Alluminio		0.3086 $(m^2\cdot K)/W$	3.2400 $W/(m^2\cdot K)$	0.62	Stato di Fatto	None
F48	1710 x 1500	42	Vetro Doppio Serramento Alluminio		0.3030 $(m^2\cdot K)/W$	3.3000 $W/(m^2\cdot K)$		Stato di Fatto	None
F49	700 x 700	6	Vetro Singolo Serramento Alluminio Vetro Singolo Serramento Alluminio Vetro Singolo Serramento Alluminio		0.2155 $(m^2\cdot K)/W$	4.6400 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F50	1400 x 1500	4	Vetro Doppio Serramento Alluminio Vetro Doppio Serramento Alluminio		0.2632 $(m^2\cdot K)/W$	3.8000 $W/(m^2\cdot K)$	0.76	Stato di Fatto	None
Edificio 2 Piano Prima									
F47	1890 x 1500	48	Vetro Doppio Serramento Alluminio		0.3086 $(m^2\cdot K)/W$	3.2400 $W/(m^2\cdot K)$	0.62	Stato di Fatto	None
F49	700 x 700	9	Vetro Singolo Serramento Alluminio Vetro Singolo Serramento Alluminio Vetro Singolo Serramento Alluminio		0.2155 $(m^2\cdot K)/W$	4.6400 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F50	1400 x 1500	4	Vetro Doppio Serramento Alluminio Vetro Doppio Serramento Alluminio		0.2632 $(m^2\cdot K)/W$	3.8000 $W/(m^2\cdot K)$	0.76	Stato di Fatto	None
Edificio 2 Piano Terra									
F07	900 x 900	66	Vetro Singolo Serramento Alluminio		0.2155 $(m^2\cdot K)/W$	4.6400 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F47	1890 x 1500	44	Vetro Doppio Serramento Alluminio		0.3086 $(m^2\cdot K)/W$	3.2400 $W/(m^2\cdot K)$	0.62	Stato di Fatto	None
F49	700 x 700	9	Vetro Singolo Serramento Alluminio Vetro Singolo Serramento Alluminio Vetro Singolo Serramento Alluminio		0.2155 $(m^2\cdot K)/W$	4.6400 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F50	1400 x 1500	4	Vetro Doppio Serramento Alluminio Vetro Doppio Serramento Alluminio		0.2632 $(m^2\cdot K)/W$	3.8000 $W/(m^2\cdot K)$	0.76	Stato di Fatto	None
Edificio 2 Tetto									
F51	400 raggio	24	Lucernario plexiglass Lucernario plexiglass Lucernario plexiglass Lucernario plexiglass Lucernario plexiglass		0.2488 $(m^2\cdot K)/W$	4.0200 $W/(m^2\cdot K)$		Stato di Fatto	None
Edificio 3 Piano Interrato									
F52	2500 x 1500	2	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F52	3200 x 1500	24	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F53	6500 x 1500	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.74	Stato di Fatto	None
F54	6540 x 2000	2	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F55	4600 x 2000	12	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F56	3750 x 2000	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F57	2800 x 2000	2	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F58	1750 x 1640	2	Vetro Singolo Serramento Alluminio	0.00	0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.74	Stato di Fatto	None
F59	2400 x 1200	5	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F60	1500 x 1600	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F61	3200 x 1500	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F62	2900 x 1500	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F62	3200 x 1500	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F63	3200 x 1500	2	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F64	500 x 500	5	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
F65	750 x 2500	2	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.78	Stato di Fatto	None
Edificio 3 Piano Primo									
F52	2500 x 1500	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F52	3200 x 1500	22	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F53	6500 x 1500	1	Vetro Singolo Serramento Alluminio		0.2174 $(m^2\cdot K)/W$	4.6000 $W/(m^2\cdot K)$	0.74	Stato di Fatto	None
F61	3200 x 1500	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None
F62	3200 x 1500	1	Vetro Doppio Serramento Alluminio		0.3484 $(m^2\cdot K)/W$	2.8700 $W/(m^2\cdot K)$		Stato di Fatto	None

Table 13 Showing Characteristics of windows in Amaldi Sraffa complex.

Table 13 presents an example from the project with the characteristics of windows in the Amaldi Sraffa complex, detailing whether they are single or double-glazed. It includes window types, their designated names, dimensions, thermal properties, and quantities. This table provides a clear overview of the thermal efficiency of each window type, supporting energy performance analysis within the building.

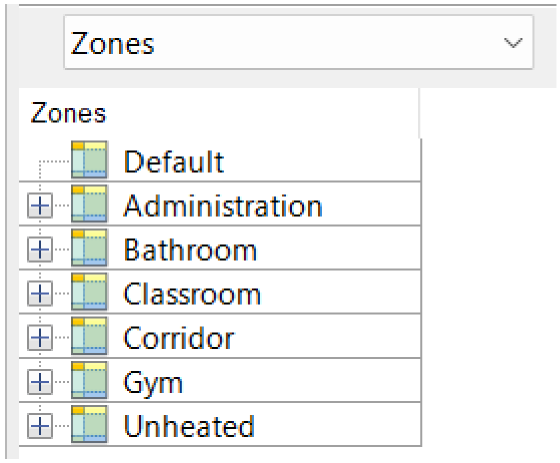
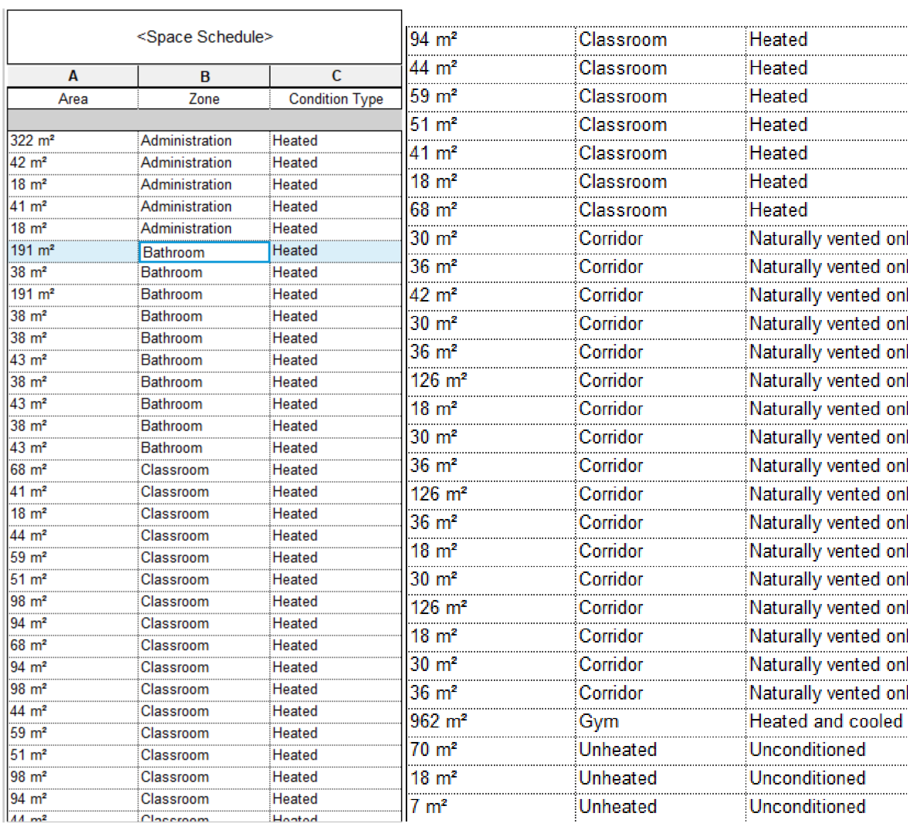


Figure 39 Creating Zones with existing information



<Space Schedule>

A	B	C
Area	Zone	Condition Type
322 m²	Administration	Heated
42 m²	Administration	Heated
18 m²	Administration	Heated
41 m²	Administration	Heated
18 m²	Administration	Heated
191 m²	Bathroom	Heated
38 m²	Bathroom	Heated
191 m²	Bathroom	Heated
38 m²	Bathroom	Heated
38 m²	Bathroom	Heated
43 m²	Bathroom	Heated
38 m²	Bathroom	Heated
43 m²	Bathroom	Heated
38 m²	Bathroom	Heated
43 m²	Bathroom	Heated
68 m²	Classroom	Heated
41 m²	Classroom	Heated
18 m²	Classroom	Heated
44 m²	Classroom	Heated
59 m²	Classroom	Heated
51 m²	Classroom	Heated
98 m²	Classroom	Heated
94 m²	Classroom	Heated
68 m²	Classroom	Heated
94 m²	Classroom	Heated
98 m²	Classroom	Heated
44 m²	Classroom	Heated
59 m²	Classroom	Heated
51 m²	Classroom	Heated
98 m²	Classroom	Heated
94 m²	Classroom	Heated
44 m²	Classroom	Heated
94 m²	Classroom	Heated
44 m²	Classroom	Heated
59 m²	Classroom	Heated
51 m²	Classroom	Heated
41 m²	Classroom	Heated
18 m²	Classroom	Heated
68 m²	Classroom	Heated
30 m²	Corridor	Naturally vented onl
36 m²	Corridor	Naturally vented onl
42 m²	Corridor	Naturally vented onl
30 m²	Corridor	Naturally vented onl
36 m²	Corridor	Naturally vented onl
126 m²	Corridor	Naturally vented onl
18 m²	Corridor	Naturally vented onl
30 m²	Corridor	Naturally vented onl
36 m²	Corridor	Naturally vented onl
126 m²	Corridor	Naturally vented onl
36 m²	Corridor	Naturally vented onl
18 m²	Corridor	Naturally vented onl
30 m²	Corridor	Naturally vented onl
126 m²	Corridor	Naturally vented onl
18 m²	Corridor	Naturally vented onl
30 m²	Corridor	Naturally vented onl
36 m²	Corridor	Naturally vented onl
962 m²	Gym	Heated and cooled
70 m²	Unheated	Unconditioned
18 m²	Unheated	Unconditioned
7 m²	Unheated	Unconditioned

Figure 40 Space Schedules

Schedules regarding Space and Zones are also created in this phase. These schedules allow to document parameters such as area, space count, names, and environmental conditions (e.g., heated, unheated, ventilated) which allows to have a clear overview of spatial and environmental attributes of the buildings.

By creating a detailed model of the Amaldi-Sraffa complex in Revit using BIM, it becomes possible to conduct energy analyses, leveraging the structural, material, and thermal properties embedded in the model. This enables an assessment of the building's current energy performance. Additionally, BIM facilitates the comparison of different strategies for improving energy efficiency, enhancing insulation. By simulating and analyzing various approaches, more sustainable solutions can be implemented, improving the existing conditions, and optimizing energy use in the complex.

Down below it is possible to see some 3D views from Revit program showing views of Amaldi Sraffa complex.

Figure 41 3D view of Building 3 North-East Façade

Figure 42 3D view of Building 2 South-East Façade

Figure 43 3D view of Building 2 West Façade

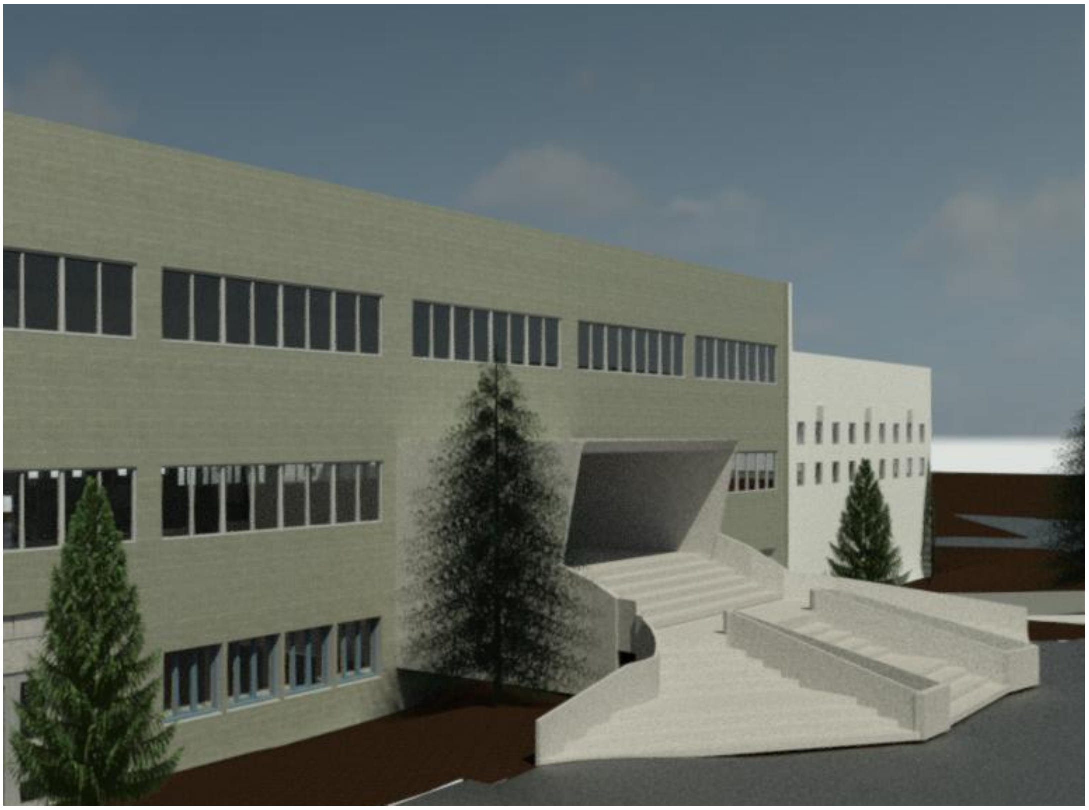


Figure 44 3D view of Building 1 East Façade Entrance

5.1 LOD For Existing School Complex

Defining the Level of Development (LOD) for existing models is essential for clarity, collaboration, and planning in BIM projects. It specifies the degree of detail and accuracy in the model and shows how reliable each element is. This ensures that stakeholders have an accurate understanding of existing conditions, which supports effective decision-making and planning for project development.

To assign LOD for an existing model, each element's geometry, associated data, and level of verification will be assessed according to the applicable LOD standards. To achieve a more accurate LOD assessment, the building will be divided into distinct parts. This breakdown includes structural elements, walls, windows and doors, roofs, floors, and basements, as well as external features such as parking areas and landscaping like trees. By evaluating each section independently, it can be ensured for each part meets the appropriate LOD standard, allowing for a precise understanding of the building's details and data quality.

A) Structural Elements

In order to determine LOD of the structural elements the existing point clouds and CAD drawings are utilized. Thanks to the point cloud, exact location, size and orientation and material of structural elements can be determined. Also, for some structural elements from the document 'Thermal and hygrometric characteristics of the opaque components of the envelope' (according to Ministerial Decree 13.12.93-Table 1 and UNI 10344) more information can be found. This information consists of thermal and hygrometric characteristics.

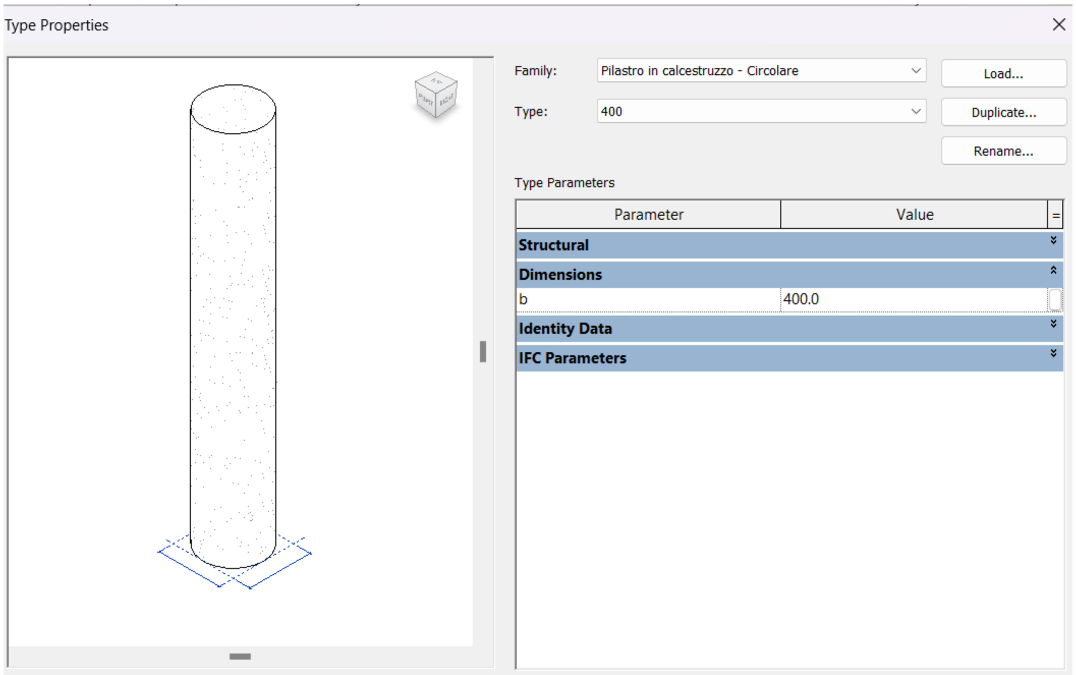


Figure 45 Structural Element properties

The model includes extensive details for structural elements, covering aspects like size, orientation, thermal properties, and installation date but lacks cost information. This places the elements at LOD 400, which involves specifications on materials, installation, and performance. However, due to the missing cost data, the model does not qualify for LOD 500. Achieving LOD 500 would require a complete set of operational and financial details, including any updates made post-construction, to support in-depth facility management.

B) Walls

To establish the LOD of the walls, existing point clouds and CAD drawings are examined. The point cloud data provides precise information on the walls' location, dimensions, orientation, and materials. Additionally, some walls' thermal and hygrometric properties can be derived from the document titled 'Thermal and Hygrometric Characteristics of the Opaque Components of the Envelope' (in accordance with Ministerial Decree 13.12.93-Table 1 and UNI 10344), enhancing the level of detail with specific energy performance characteristics.

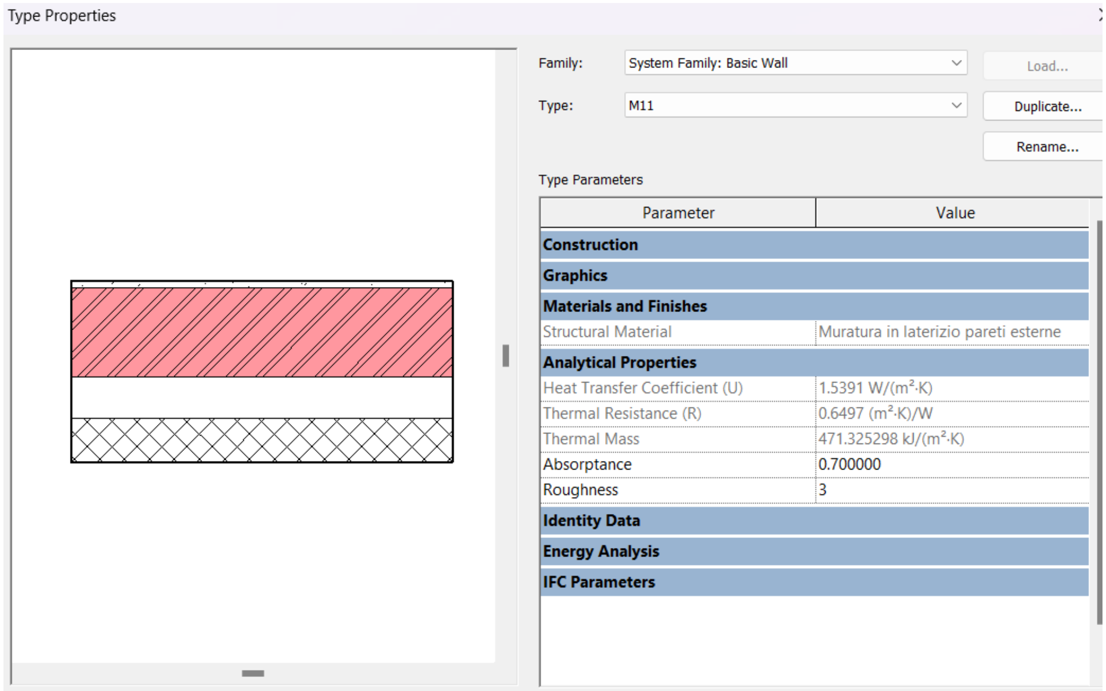


Figure 46 Wall Properties

The model provides comprehensive information on the wall elements, such as size, orientation, thermal characteristics, and installation year, yet lacks cost data. This means the wall elements could be classified as LOD 400, which includes detailed specifications on installation, materials, and performance. However, without cost information, the model does not meet the requirements for LOD 500, which would necessitate complete operational and financial details, including any modifications made post-construction, for full facility management integration.

C) Windows and Doors

To determine the LOD for windows and doors, existing point cloud data is analyzed to accurately capture their location, size, and orientation. In addition, thermal and hygrometric properties are referenced from the document Thermal and Hygrometric Characteristics of the Opaque Components of the Envelope (aligned with Ministerial Decree 13.12.93-Table 1 and UNI 10344). This document provides material information and energy performance characteristics, improving model accuracy. Furthermore, it allows for identifying specific door types, such as emergency doors, enhancing the level of detail in the model.

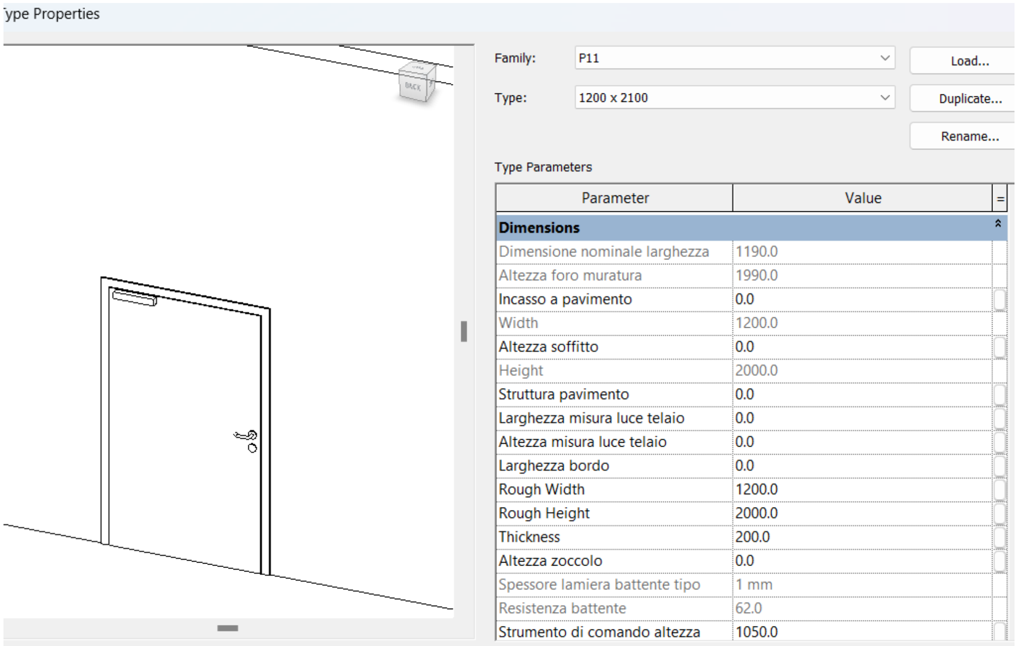


Figure 47 Door Properties

The model consists of information for doors and window element's size, orientation, thermal properties, installation year, etc. but excluding cost data, doors and windows would likely be at LOD 400 as-built documentation. This level includes detailed information about installation methods, materials, and performance data. However, the absence of cost data means that the model wouldn't fully meet the criteria for LOD 500 facility management, which would require all operational and cost data, including any post-construction changes.

D) Roofs

To establish the LOD for the roofs, existing point cloud data is reviewed to capture precise details on their location, size, and orientation. Additionally, thermal and hygrometric properties are drawn from the document Thermal and Hygrometric Characteristics of the Opaque Components of the Envelope (in accordance with Ministerial Decree 13.12.93-Table 1 and UNI 10344). This reference provides layered material information and energy performance metrics, enhancing the model's accuracy with specific material details, thus refining the overall level of detail.

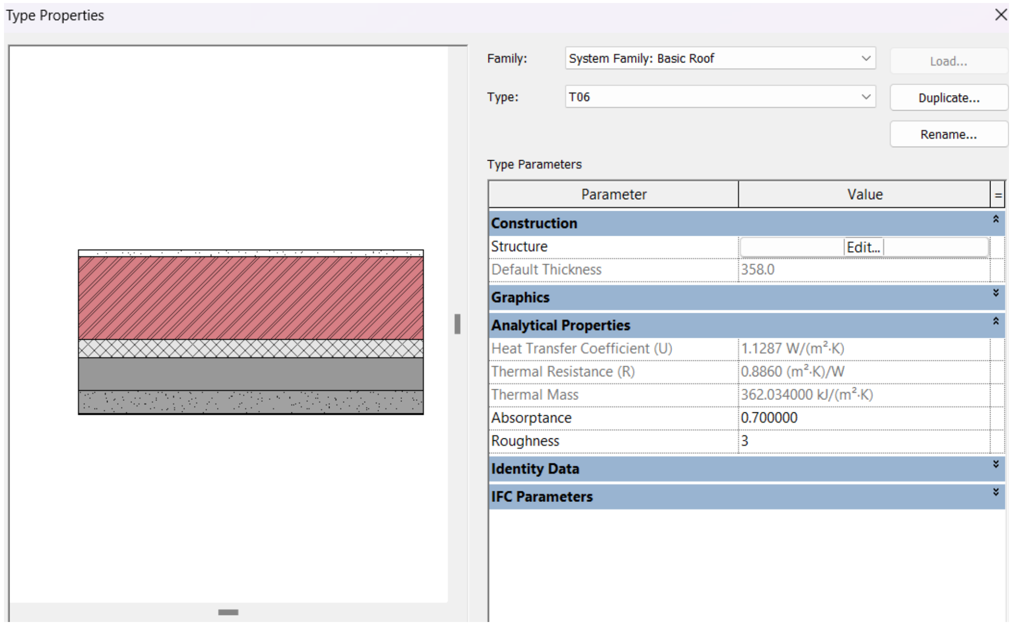


Figure 48 Roof Properties

As with other structural elements, the model for roof components includes information such as dimensions, orientation, thermal properties, and installation date but lacks cost data. This categorizes the roof elements at LOD 400, which provides detailed material specifications, installation methods, and performance characteristics. However, due to the absence of cost information, the model does not fulfill the criteria for LOD 500. To achieve LOD 500, a complete set of operational and financial details, including any post-construction modifications, would be necessary to facilitate full facility management integration.

E) Floors And Basements

The existing point cloud data is used to accurately capture the location, size, and orientation of floors and basements. Additionally, the thermal and hygrometric properties of these elements are derived from the document Thermal and Hygrometric Characteristics of the Opaque Components of the Envelope (aligned with Ministerial Decree 13.12.93-Table 1 and UNI 10344). This information includes detailed material properties and energy performance characteristics, which enhance the model's accuracy by integrating specific material details and improving its overall level of detail.

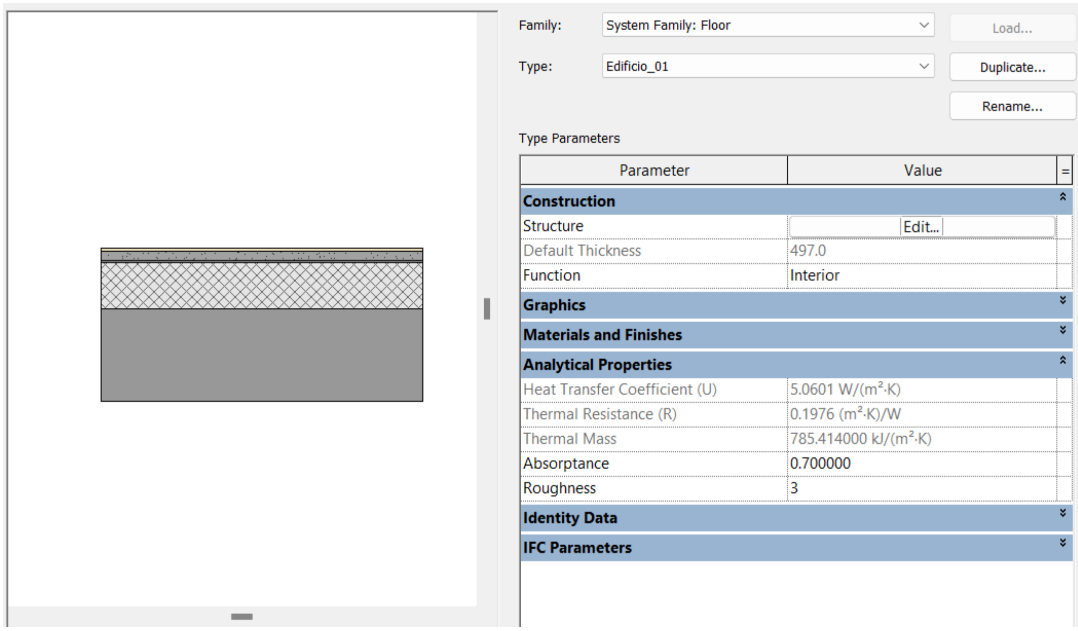


Figure 49 Floor Properties

Like other structural components, the model for the floors and basement includes data on dimensions, orientation, thermal properties, and installation date, but it lacks cost information. This positions these elements at LOD 400, which entails detailed specifications on materials, installation methods, and performance attributes. However, the model does not meet LOD 500 standards, as this level would require comprehensive operational and financial data, including any adjustments made post-construction.

F) External Features

In this context, external features include terrain characteristics, existing trees, parking lots, and similar elements. Using the available documentation, details such as the age, type, and dimensions of the trees were determined and integrated into the model. For other external features, such as parking lots or terrain, the existing point cloud data was analyzed to accurately capture their location, size, and orientation, providing a precise representation of these elements in the model.

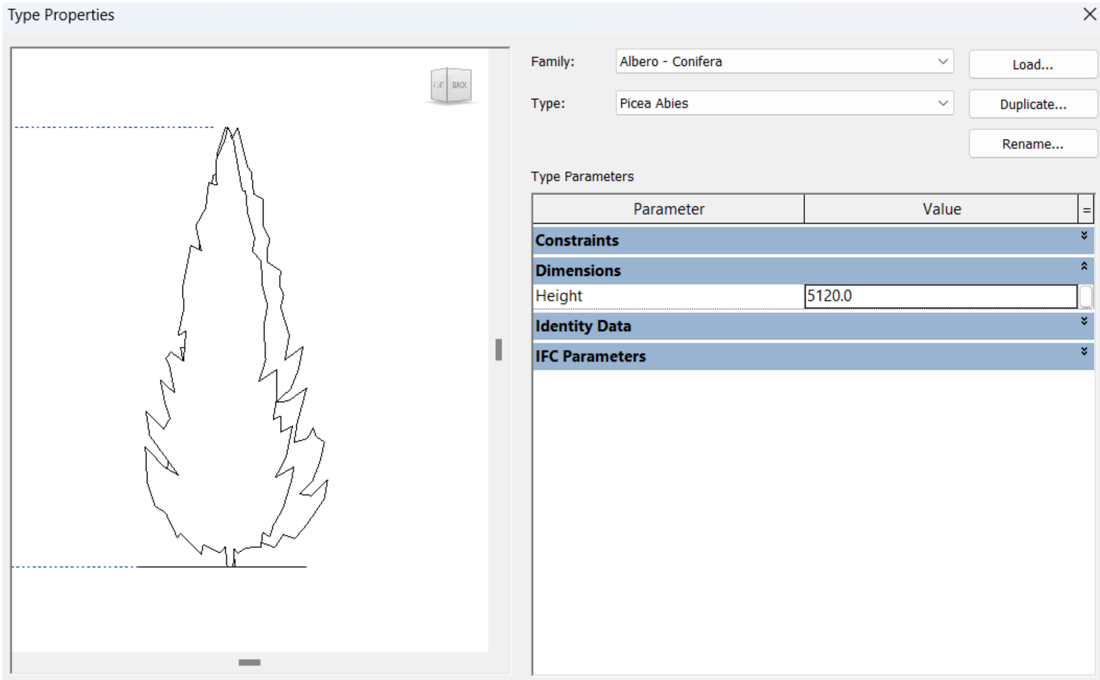


Figure 50 Tree Properties

The model for external features includes details like dimensions, orientation, and installation date but lacks key data such as cost and some thermal properties, placing it below LOD 400. While type, quantity, size, and shape are available, additional information is needed to achieve a higher level of detail. Currently, with the provided data, the external features align with LOD 300. To improve the model's accuracy and meet higher LOD standards, it's essential to incorporate more data on performance and costs.

G) Evaluation of LOD for Existing School Complex

To assess the LOD of an existing model, each building element's geometry, data, and verification level are evaluated based on LOD standards. The building is divided into categories—such as structural elements, walls, windows, doors, roofs, floors, basements, and external features like parking and landscaping. This organized approach ensures each part meets the appropriate LOD, providing a precise view of the model's detail and data quality. The table below summarizes LOD information for each building component.

Building Categories	LOD Information
Structural Elements	LOD 400
Walls	LOD 400
Windows and Doors	LOD 400
Roofs	LOD 400
Floors and Basements	LOD 400
External Elements	LOD 300

Table 14 LOD information for Existing School Complex

5.2 Integration with Edilclima Software

After developing the BIM as-built model for the Amaldi Sraffa Complex, Edilclima software will be used to perform energy efficiency calculations in compliance with Italian regulations and standards. To ensure accurate and reliable results, it is essential to first establish a detailed as-is model of the existing conditions. This model will serve as the baseline for comparing various energy efficiency strategies, providing a consistent foundation for evaluating alternative approaches.

For the Amaldi Sraffa building implementations, the EC770 Plug-in for Revit is utilized for the Edilclima software. This method is preferred as it facilitates the transfer of materials and shading elements directly from the Revit model to the Edilclima energy analysis software EC700. (Edilclima, n.d.)

For Edilclima to accurately transfer information about external facades and materials, it is crucial to correctly configure these details in the BIM model. Once this information is properly set, Edilclima works with the thermal zones defined in the BIM model to integrate and process the relevant data for energy analysis. This ensures communication between the two systems and enables precise energy efficiency calculations.

It has been observed that adding space and zone tags to the existing zones is essential for achieving a seamless transfer of information to Edilclima. Another crucial step is exporting the Revit model as an IFC file, which allows for the efficient transfer of data between Revit and Edilclima for accurate energy performance analysis.

When exporting the existing model as an IFC file, simplifying elements such as terrain, non-shading external components, and trees helps ensure that the results generated by the software are more accurate and consistent. This refinement minimizes unnecessary data, focusing the analysis on key factors that directly influence energy performance. (Ugliotti, Dellosta, & Osello, 2016)

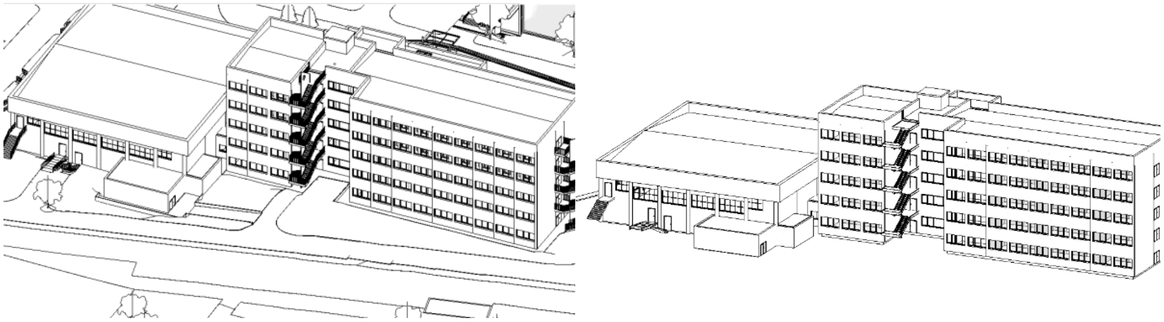


Figure 51 Existing Revit model vs simplified version for energy model

In the next step, using the Edilclima plugin EC770 in Revit enables the export of model information to the Edilclima software. This process allows for the efficient transfer of data necessary for energy analysis, ensuring that all relevant information regarding the building's design is accurately conveyed for further evaluation and optimization.

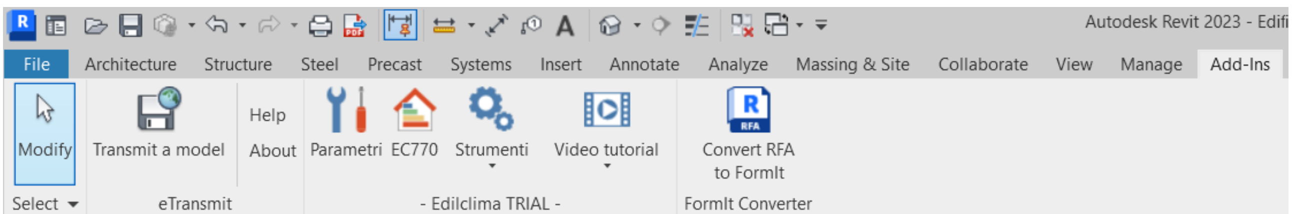


Figure 52 shows the Edilclima plugin integrated into the Revit software.

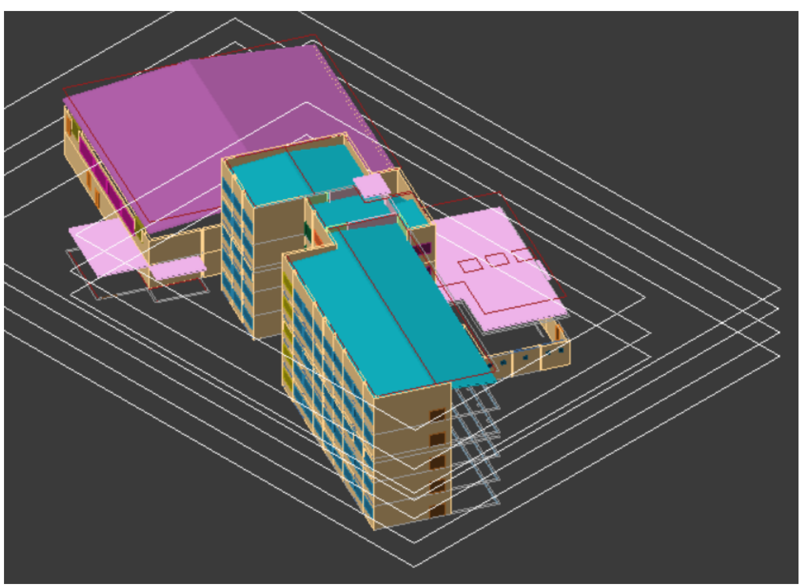


Figure 53 Exporting existing building to Edilclima with EC770 plugin.

The figure demonstrates the accuracy with which the software has recreated the model using the information provided from the BIM model. This highlights the effectiveness of the data transfer and the software's ability to generate a reliable representation of the original design with the zones and spaces created at Revit.

Next step is filling necessary information regarding the climate data of the project site at Edilclima EC700 Software.

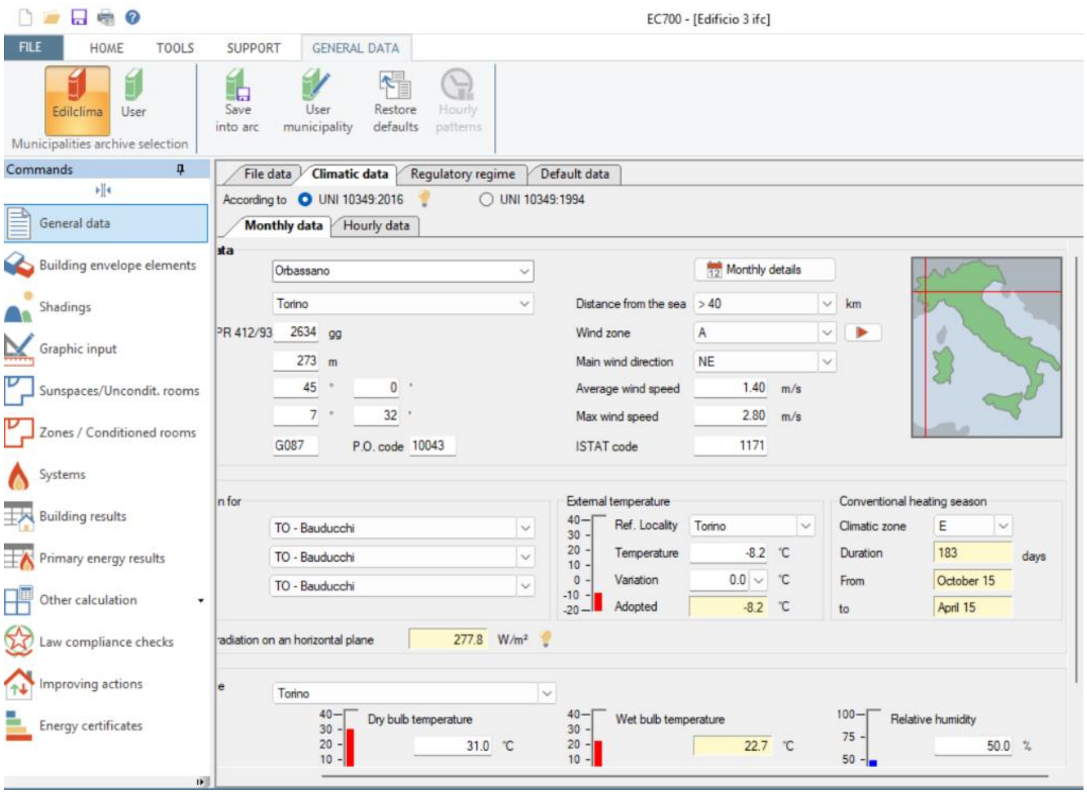


Figure 54 Inputting Climatic Data to Edilclima Application

After inputting manually all necessary information from the existing APE document—covering aspects such as winter heating systems, summer cooling systems, mechanical ventilation, lighting, hot water production, and energy sources—the energy model has been established. This model leverages accurate data, ensuring its reliability as a basis for incoming analysis. With this energy analysis is in place, the next steps will involve comparing various energy efficiency solutions, allowing for informed decision-making in optimizing the building's performance and sustainability.

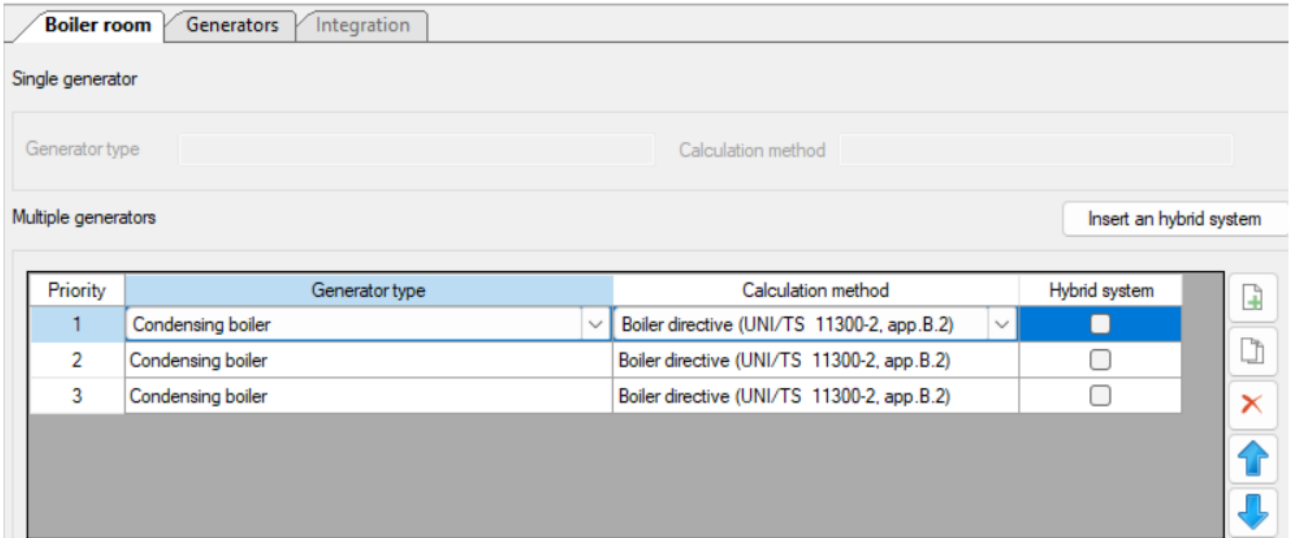


Figure 55 Inputting manually system information.

Using the BIM and Edilclima model that has been created, the upcoming section will evaluate the approaches for enhancing the energy efficiency of the Amaldi-Sraffa complex. Each approach will be analyzed for its economic feasibility and sustainability. The design hypotheses will be organized into two categories. The first category focuses on reducing energy consumption for the Amaldi Sraffa high school building. The first approach involves integrating solar panels into the existing structure, while the second approach emphasizes replacing the current condensing boilers with high-efficiency models. The second category addresses insulation, where three approaches will be analyzed: optimizing green roofs, using the existing roof's insulation with EPS, and implementing insulation with Wood Fiber Panels (WFP).

6. DESIGN HYPOTHESIS FOR SCHOOL COMPLEX AMALDI WITH USE OF BIM AND EDILCLIMA

6.1 Design Hypothesis Regarding Energy Efficiency

6.1.1 Solar Panel Integration

The first design approach regarding energy efficiency for the L.S. Amaldi in Orbassano focuses on integrating solar panels to enhance energy efficiency. This strategy aims to reduce the building's environmental impact and to establish the L.S. Amaldi project as a model for future sustainable architecture initiatives. By incorporating renewable energy solutions, the school complex can serve as a case study, highlighting the potential for energy-efficient design in educational facilities.

According to Britannica, solar panels, or photovoltaic (PV) panels, are devices that convert sunlight into electricity through the photoelectric effect. Solar panels generate electricity when sunlight strikes the PV cells, exciting electrons and creating an electric current.

The sun is a source of clean and sustainable electricity that doesn't produce toxic pollution or contributes to global warming. Using solar energy is good for the environment because it helps reduce the reliance on fossil fuels and significantly cuts down greenhouse gas emissions compared to traditional energy sources. Additionally, solar photovoltaic (PV) cells generate electricity without using any water, making them an eco-friendly option (Environmental Impacts of Solar Power, 2013)

According to data from Comunità Energetiche Rinnovabili e Solidali (C.E.R.S), Italy has over 40,000 existing school buildings, and if photovoltaic panels were installed on the roofs of all these schools, the estimated energy production would reach 1 TWh annually. This output would be sufficient to meet the energy needs of 400,000 households (Ecosistema scuola, 2023) Given this huge potential, integrating solar panels into school buildings is a highly promising strategy, making it a focus point for the Amaldi School complex case study to explore sustainable energy solutions.

Based on (Ecosistema scuola, 2023), 21.8% of schools in Italy are equipped with renewable energy systems, with 78.4% of those relying on photovoltaic panels. This demonstrates that solar energy is an approach adapted in Italian schools. The goal of the design approach research is to show how the Amaldi School complex's integration of photovoltaic panels might function as a theoretical model that other schools across the nation may be able to adopt as well.

Regulatory Framework and Financial Incentives

According to Legislative Decree n. 28/2011, at least 55% of the building's energy needs for heating, cooling, and domestic hot water (DHW) must come from renewable sources. In this case the renewable energy source is PV panels.

UNI/TS 11300-4 technical standards are established to assess energy performance of buildings. It is a part of a larger set of guidelines that direct the use of renewable energy technologies and energy efficiency measures in buildings. It complies with the Energy Performance of buildings Directive (EPBD) of the European Union, which requires member states to set energy performance requirements for structures. UNI/TS 11300-4 is applicable to several types of buildings, including residential, commercial, and institutional structures. It addresses both new constructions and existing buildings undergoing retrofitting. (UNI/TS 11300-4:2016)

According to the data from International Energy Agency (IEA), 2020 in the last 15 years due to competition at the sector prices for PV standard module crystalline silicon reduced to 0,16 euro per [€/W] from 2,30 euro[€/W]. Meaning that trend is lower prices for the installation of solar panels.

There are also financial incentives available through Conto Termico 2.0 to support the integration of renewable energy in school building retrofits in Italy. Conto Termico 2.0 is an Italian incentive program designed to promote the use of renewable energy sources and improve energy efficiency in buildings. (Conto Termico, n.d.)

Characteristics Of the Solar Panels

Solar panels come in several types, with the most common being monocrystalline, polycrystalline, and thin-film panels. Monocrystalline panels are known for their high efficiency and durability, as they are made from a single crystal structure of silicon. In contrast, polycrystalline panels are constructed from multiple silicon crystals, making them less expensive but also less efficient than monocrystalline panels. Thin-film panels, on the other hand, are lightweight and flexible, allowing for a variety of applications; however, they typically have lower efficiency compared to the other two types. This diversity in solar panel technology provides options to suit different needs and budgets (Photovoltatics, n.d.)

Photovoltaic plants in Italy use silicon-based panels 72.5% of the existing panels in Italy consist of polycrystalline silicon panels, while 21.5% use monocrystalline silicon. The remaining 6% are composed of thin films or other advanced, higher-performing materials. (How much solar energy Italy produces and where it’s produced, n.d.)

There are also new advancements in the solar panels industry. One of these advancements is double sided solar panels. They are solar panels that can absorb solar energy from both faces instead of only one face. And data from Clemente (2024) shows that they are up to %10-20 more efficient than single side panels, although they require greater distance from the ground for optimal light capture and costs higher compared to conventional modules.

Photovoltaic (PV) panels typically have a lifespan of 25-30 years, with manufacturers often guaranteeing performance for over 20 years and are recyclable and recycling them reduces environmental damage and recovers rare materials. (Artaş, Kocaman, Bilgiç, Tutumlu, & Yumrutaş, 2023)

Considering all the information regarding advancements for the solar panels in Italian market, for the Orbassano school building project, polycrystalline silicon panels have been chosen for the rooftops, prioritizing for cost-effectiveness, ease of maintenance and widespread availability in the market. These panels, which are widely used in Italy, provide a reliable and economical solution for integrating renewable energy into the school's design, aligning with the project's sustainable architecture goals.

Technical Information of Solar Panels

According to the Solar PV analysis of Turin by Robinson, A., the optimal angle for fixed solar panels in Orbassano should be 39° facing south. This angle allows for maximum solar exposure throughout the year, ensuring efficient energy capture. While modifiable solar panels can be adjusted for even better performance—29° for the summer months and 59° for the winter months, both facing south—the increased cost and complexity associated with adjustable systems make them less practical for the context of school buildings.

Considering the financial constraints and maintenance challenges of non-fixed panels in school settings, fixed panels at a 39° angle will be assumed for the calculations.

Based on the data from Walch et al. (2021), it is common to utilize around 70-75% of the available roof space when planning for the installation of photovoltaic (PV) panels. This percentage takes into consideration factors such as shading, structural limitations, and space for necessary maintenance pathways. By strategically using this portion of the roof, the design optimizes energy production while accounting for practical constraints. For the school building in Orbassano, adopting this strategy will allow for optimal integration of PV systems while maintaining the functionality and safety of the roof structure. For the necessary calculations, a maximum of 75% of the existing roof space is used to estimate the potential energy output and feasibility of the installation. (Walch, Rüdisüli, Castello, & Scartezzini, 2021)

Application of Edilclima Software

To obtain results that align with the laws and regulations in Italy for retrofitting school buildings, the BIM software Revit and the Edilclima software will be used together. With Edilclima software it is possible to get results according to UNI/TS 11300-4 technical standards (*Edilclima*, n.d.).

To achieve results for the photovoltaic solar systems, Edilclima' s specific module regarding solar panels EC713 Module is going to be used.

After installing the module, the project information is added according to the existing BIM model.

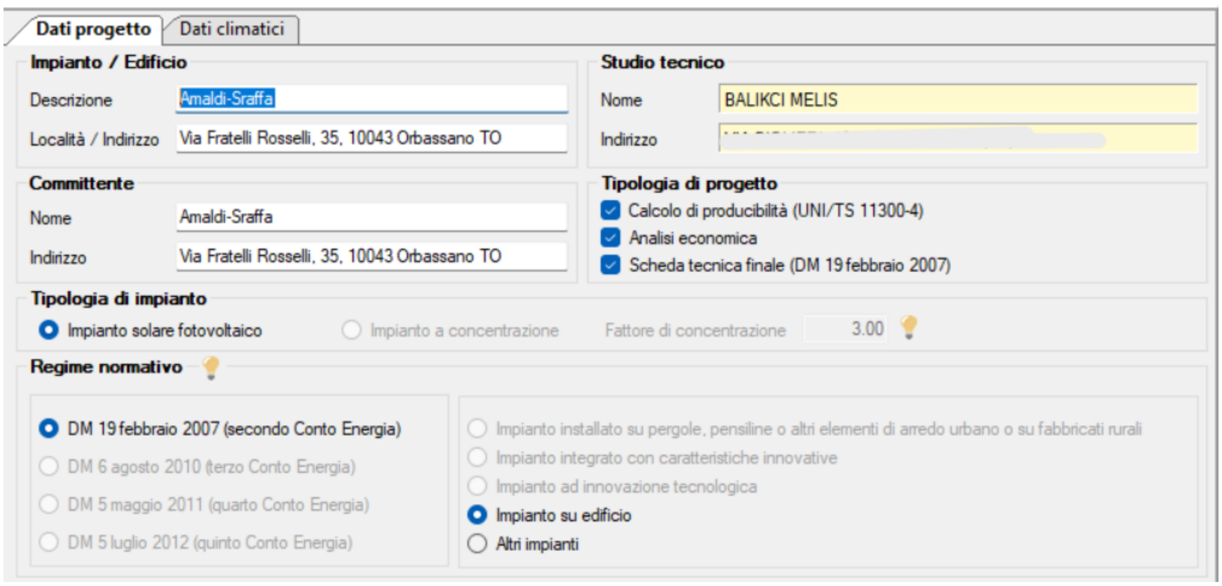
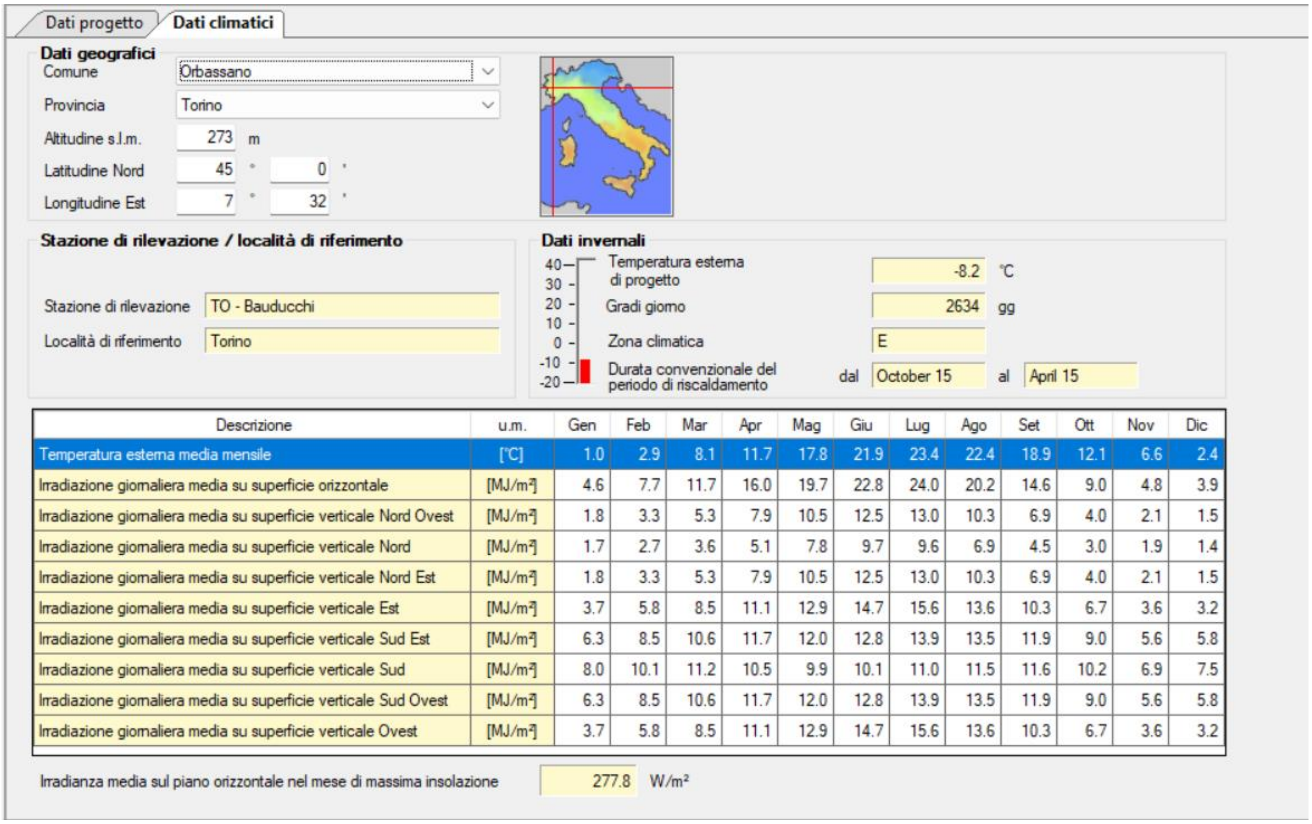


Figure 56 Screenshot from Edilclima EC713 Module.

As can be observed, the module that permits calculations is conducted in compliance with UNI/TS 11300-4 Technical Specification.

Next step is filling necessary information regarding the climate data of the project site.

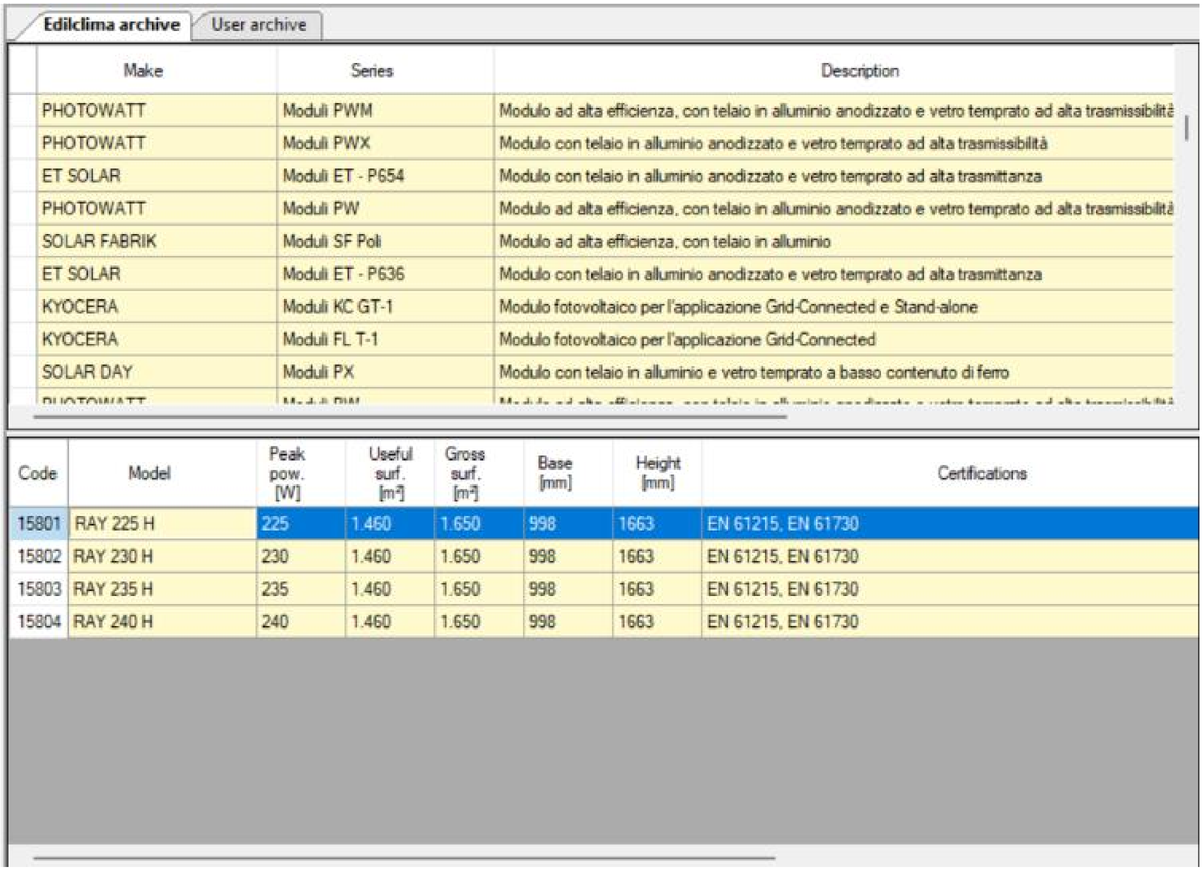


Descrizione	u.m.	Gen	Feb	Mar	Apr	Mag	Giu	Lug	Ago	Set	Ott	Nov	Dic
Temperatura esterna media mensile	[°C]	1.0	2.9	8.1	11.7	17.8	21.9	23.4	22.4	18.9	12.1	6.6	2.4
Irradiazione giornaliera media su superficie orizzontale	[MJ/m²]	4.6	7.7	11.7	16.0	19.7	22.8	24.0	20.2	14.6	9.0	4.8	3.9
Irradiazione giornaliera media su superficie verticale Nord Ovest	[MJ/m²]	1.8	3.3	5.3	7.9	10.5	12.5	13.0	10.3	6.9	4.0	2.1	1.5
Irradiazione giornaliera media su superficie verticale Nord	[MJ/m²]	1.7	2.7	3.6	5.1	7.8	9.7	9.6	6.9	4.5	3.0	1.9	1.4
Irradiazione giornaliera media su superficie verticale Nord Est	[MJ/m²]	1.8	3.3	5.3	7.9	10.5	12.5	13.0	10.3	6.9	4.0	2.1	1.5
Irradiazione giornaliera media su superficie verticale Est	[MJ/m²]	3.7	5.8	8.5	11.1	12.9	14.7	15.6	13.6	10.3	6.7	3.6	3.2
Irradiazione giornaliera media su superficie verticale Sud Est	[MJ/m²]	6.3	8.5	10.6	11.7	12.0	12.8	13.9	13.5	11.9	9.0	5.6	5.8
Irradiazione giornaliera media su superficie verticale Sud	[MJ/m²]	8.0	10.1	11.2	10.5	9.9	10.1	11.0	11.5	11.6	10.2	6.9	7.5
Irradiazione giornaliera media su superficie verticale Sud Ovest	[MJ/m²]	6.3	8.5	10.6	11.7	12.0	12.8	13.9	13.5	11.9	9.0	5.6	5.8
Irradiazione giornaliera media su superficie verticale Ovest	[MJ/m²]	3.7	5.8	8.5	11.1	12.9	14.7	15.6	13.6	10.3	6.7	3.6	3.2

Figure 57 Setting up climate information of the project site.

In this part it is possible to see monthly temperature and daily solar irradiation for the months of the year and station that climate information is considered.

After entering the site information, the next step is to select the solar panels for the project. As mentioned earlier, fixed polycrystalline silicon panels with a 39° incline have been chosen. After consulting the Edilclima archive for appropriate options, the Thermital Ray 225 H PV panels were selected, which are manufactured by a producer in Italy.



Edilclima archive | User archive

Make	Series	Description
PHOTOWATT	Moduli PWM	Modulo ad alta efficienza, con telaio in alluminio anodizzato e vetro temprato ad alta trasmissibilità
PHOTOWATT	Moduli PWX	Modulo con telaio in alluminio anodizzato e vetro temprato ad alta trasmissibilità
ET SOLAR	Moduli ET - P654	Modulo con telaio in alluminio anodizzato e vetro temprato ad alta trasmittanza
PHOTOWATT	Moduli PW	Modulo ad alta efficienza, con telaio in alluminio anodizzato e vetro temprato ad alta trasmissibilità
SOLAR FABRIK	Moduli SF Poli	Modulo ad alta efficienza, con telaio in alluminio
ET SOLAR	Moduli ET - P636	Modulo con telaio in alluminio anodizzato e vetro temprato ad alta trasmittanza
KYOCERA	Moduli KC GT-1	Modulo fotovoltaico per l'applicazione Grid-Connected e Stand-alone
KYOCERA	Moduli FL T-1	Modulo fotovoltaico per l'applicazione Grid-Connected
SOLAR DAY	Moduli PX	Modulo con telaio in alluminio e vetro temprato a basso contenuto di ferro

Code	Model	Peak pow. [W]	Useful surf. [m²]	Gross surf. [m²]	Base [mm]	Height [mm]	Certifications
15801	RAY 225 H	225	1.460	1.650	998	1663	EN 61215, EN 61730
15802	RAY 230 H	230	1.460	1.650	998	1663	EN 61215, EN 61730
15803	RAY 235 H	235	1.460	1.650	998	1663	EN 61215, EN 61730
15804	RAY 240 H	240	1.460	1.650	998	1663	EN 61215, EN 61730

Figure 58 Edilclima Archive regarding the existing panel producers in Italy.

To generate 55% of the building's annual energy needs as stipulated by Legislative Decree No. 28/2011, 600 PV panels must be added. This 55% corresponds to an energy requirement of 149,200 kWh a year.

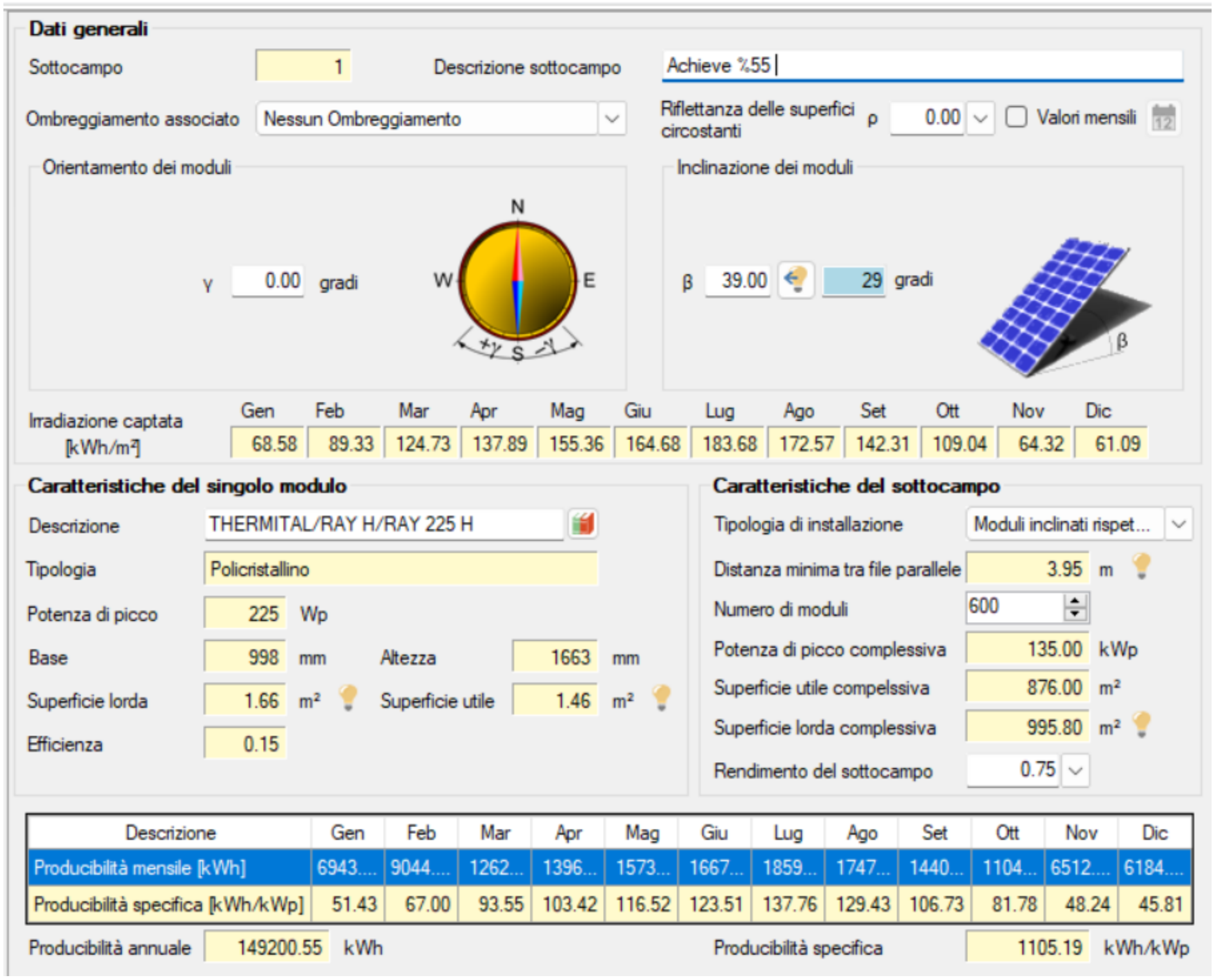
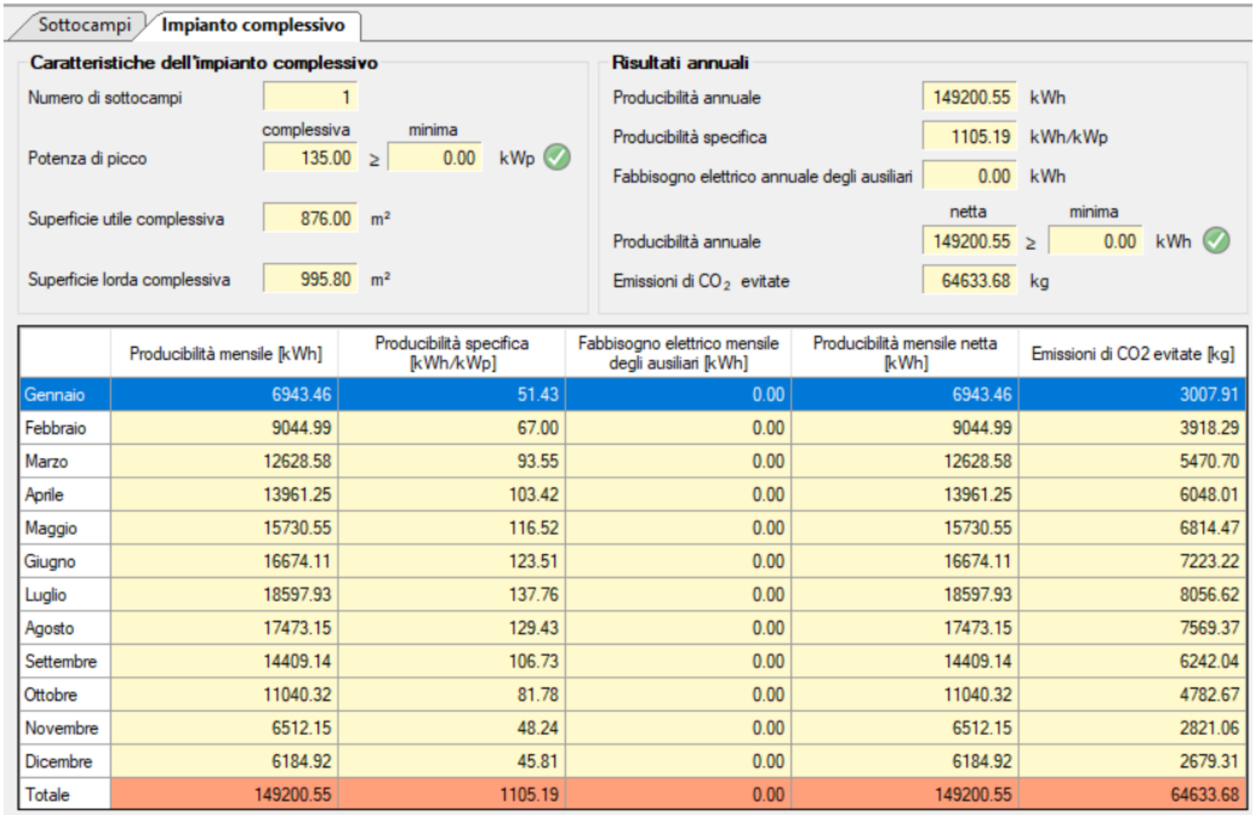


Figure 59 Approach, Covering %55 of annual energy consumption according to Legislative Decree No. 28/2011.

Given that the total roof area of the existing building is 2,040 m², the 995 m² required to cover the annual energy consumption represents 48% of the available roof space. This amount is well below the maximum limit of 75%, making the approach feasible.



Sottocampi | **Impianto complessivo**

Caratteristiche dell'impianto complessivo

Numero di sottocampi	1		
	complessiva	minima	
Potenza di picco	135.00 ≥	0.00	kWp
Superficie utile complessiva	876.00		m²
Superficie lorda complessiva	995.80		m²

Risultati annuali

Producibilità annuale	149200.55		kWh
Producibilità specifica	1105.19		kWh/kWp
Fabbisogno elettrico annuale degli ausiliari	0.00		kWh
	netta	minima	
Producibilità annuale	149200.55 ≥	0.00	kWh
Emissioni di CO_2 evitate	64633.68		kg

	Producibilità mensile [kWh]	Producibilità specifica [kWh/kWp]	Fabbisogno elettrico mensile degli ausiliari [kWh]	Producibilità mensile netta [kWh]	Emissioni di CO2 evitate [kg]
Gennaio	6943.46	51.43	0.00	6943.46	3007.91
Febbraio	9044.99	67.00	0.00	9044.99	3918.29
Marzo	12628.58	93.55	0.00	12628.58	5470.70
Aprile	13961.25	103.42	0.00	13961.25	6048.01
Maggio	15730.55	116.52	0.00	15730.55	6814.47
Giugno	16674.11	123.51	0.00	16674.11	7223.22
Luglio	18597.93	137.76	0.00	18597.93	8056.62
Agosto	17473.15	129.43	0.00	17473.15	7569.37
Settembre	14409.14	106.73	0.00	14409.14	6242.04
Ottobre	11040.32	81.78	0.00	11040.32	4782.67
Novembre	6512.15	48.24	0.00	6512.15	2821.06
Dicembre	6184.92	45.81	0.00	6184.92	2679.31
Totale	149200.55	1105.19	0.00	149200.55	64633.68

Figure 60 Screenshot from Edilclima EC713 regarding energy produced (kWh), according to the months.

The solar panels from the approach generate a net annual energy output of **149,200 kWh**. This covers %55 of annual energy demand for L.S. Amaldi High School Building. This significant amount of renewable energy contributes directly to reducing reliance on non-renewable energy sources, thereby enhancing sustainability.

The installation has avoided approximately **64 kg** of CO_2 emissions annually. This reduction illustrates the positive environmental impact of utilizing solar energy over traditional fossil fuel sources. By lowering the overall carbon footprint of the building or facility, showing the effectiveness of solar energy in combatting greenhouse gas emissions.

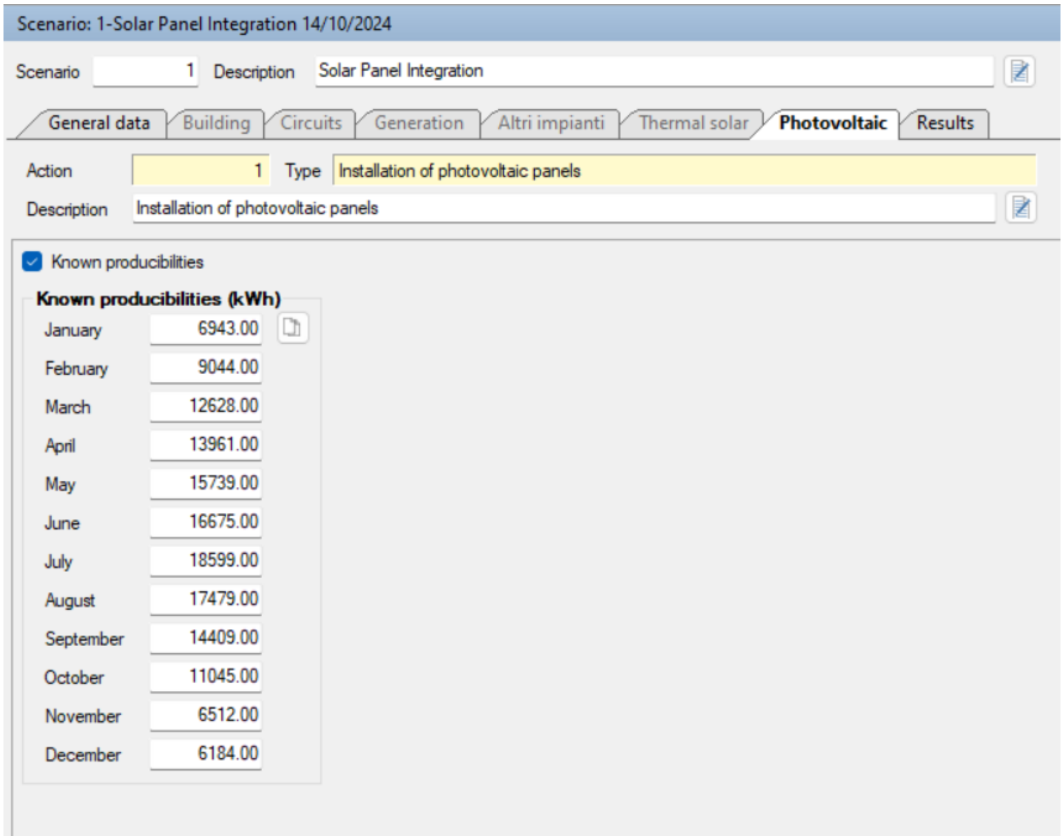


Figure 61 Transferring results to Edilclima EC 700 software

After calculating the annual producibilities with solar panel investments using Edilclima EC713 software, the results are manually transferred to EC700 software. This process allows for the calculation and comparison of various approaches by incorporating monthly energy production data and initial cost information.

Results

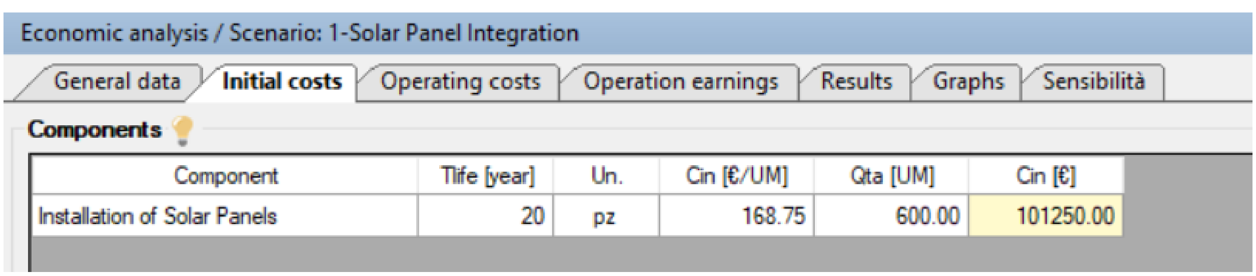
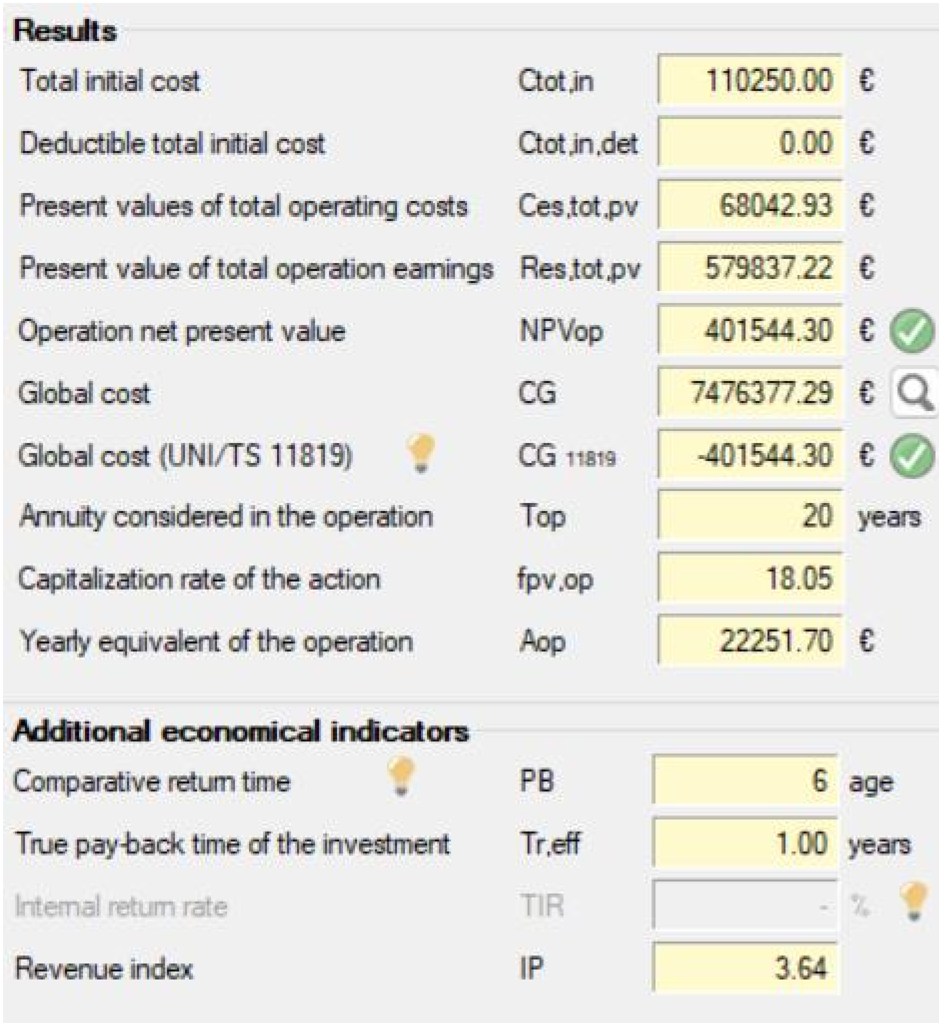


Figure 62 Initial Costs for Solar Panel Integration Approach

In the economic analysis, the cost of a single solar panel is set at 168.75 €, as stated by Prezzario (2024). The analysis is based on a financing period of 20 years with a 1% interest rate. Maintenance and insurance costs are assumed to be 5% of the total system cost, while management costs are calculated at 0.5%. Given that prices may vary depending on the region and location of the building, a 5% inflation rate for non-renewable energy sources is applied, as suggested by (Testi, 2017)



Results

Total initial cost	Ctot,in	110250.00	€
Deductible total initial cost	Ctot,in,det	0.00	€
Present values of total operating costs	Ces,tot,pv	68042.93	€
Present value of total operation earnings	Res,tot,pv	579837.22	€
Operation net present value	NPVop	401544.30	€
Global cost	CG	7476377.29	€
Global cost (UNI/TS 11819)	CG 11819	-401544.30	€
Annuity considered in the operation	Top	20	years
Capitalization rate of the action	fpv,op	18.05	
Yearly equivalent of the operation	Aop	22251.70	€

Additional economical indicators

Comparative return time	PB	6	age
True pay-back time of the investment	Tr,eff	1.00	years
Internal return rate	TIR	-	%
Revenue index	IP	3.64	

Figure 63 Economic Evaluation of Solar Panel Integration Scenario

The economic evaluation indicates that the total initial investment for the solar panel installation amounts to €110,250, which results in a payback period of approximately 6.0 years (calculated according to UNI EN 15459). This means that after this period, the savings generated from reduced energy costs will offset the initial expenditure.

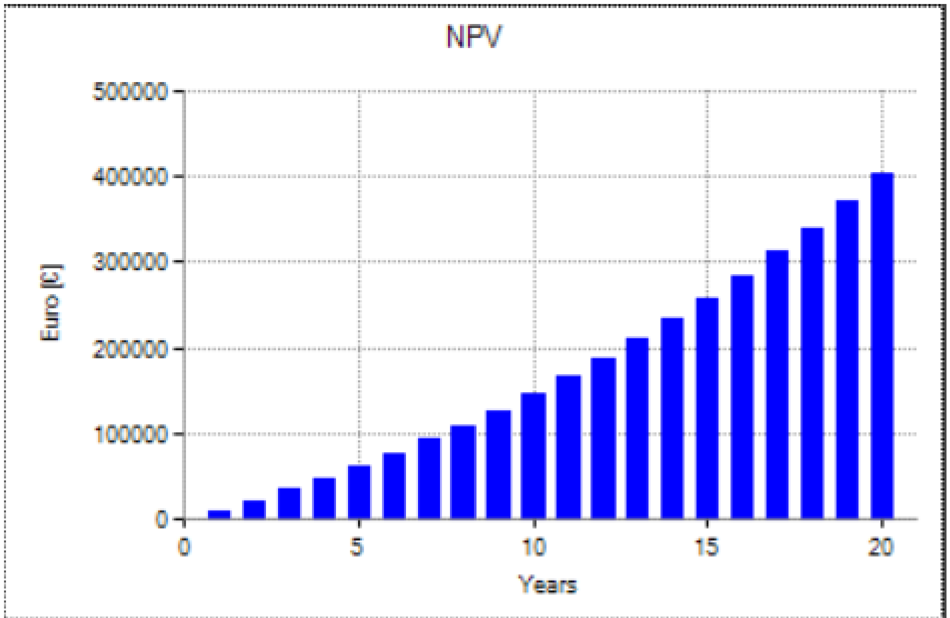


Figure 64 Graph from EC 700 regarding the investment of Solar Panels

The graph represents net present value related to the investment over time. The X axis represents time in years, starting from zero and extending beyond 20 years. This shows the time frame over which the investment's cash flows are being tracked. While Y-axis labeled in thousands of Euros, showing the magnitude of the cash flows (both negative and positive).

Blue bar is regarding Net Present Value (NPV), become positive after a certain period and continue to grow, indicating that the present value of future cash flows exceeds the initial investment costs. A positive NPV signifies that the investment is financially viable and profitable in the long run.

Evaluations

Economic evaluation

Integrating Solar panel as a solution suggests that it is profitable, with a positive NPV and positive cash flows after the initial investment period. Even though the initial cost of solar panel integration is high, the cumulative cash flow increases over time, indicating that the project not only recovers the initial investment but also generates long-term financial returns.

By including financial incentives such as Conto Termico 2.0, it is possible to reach even better the economic viability of integrating solar panels at the L.S. Amaldi High School Building. This program not only reduces the initial investment costs but also improves the overall return on investment, allowing for a more favorable economic evaluation of the solar panel installation.

Sustainable evaluation

Integration of solar panels demonstrates strong sustainability contributions through renewable energy generation and CO_2 emissions reductions. Numbers show 64 kg of CO_2 emissions annually. The ability to produce renewable energy consistently (even if there are periods of low production) ensures long-term sustainability. This approach to energy sustainability not only meets immediate energy demands but also advances long-term environmental objectives, there is potential for recycling solar panels after their operational lifespan of 25 to 30 years. The implementation of these solar panel systems aligns well with global sustainability objectives, promoting cleaner energy solutions and fostering a reduced carbon footprint for the L.S. Amaldi High School building.

Other evaluations

The existing roof must be evaluated before installment of PV panels to ensure that it can support the additional weight of solar panels and mounting equipment. Some roofs may require reinforcement when integrating solar panels approach.

Aesthetics should be considered before installing solar panels, as their visual impact can affect the overall appearance of a school building and may be a concern for some stakeholders.

6.1.2 Replacing Existing Condensing Boilers with High Efficiency Models

The second approach regarding energy efficiency is regarding condensing boilers. Condensing boilers, developed since the 1980s, initially operated as single-stage models, with fully modulating versions introduced in the mid-1990s. These boilers achieve high efficiency by capturing latent heat from water vapor in the exhaust gases. When natural gas is burned in a boiler, around 90% of the fuel's energy is transformed into sensible heat (heat that raises temperature), while approximately 10% becomes latent heat.

Unlike traditional boilers that release this latent heat in the flue gases, condensing boilers reclaim it by condensing the water vapor. This reclaimed heat is then transferred to the boiler's return water, further enhancing energy efficiency. (Cutler, 2014)

Although information on the boilers for this specific building is unavailable, information exists for the other two buildings in the complex: I.T.C. SRAFFA and I.T.I.S. AMALDI. Both have documented efficiency rates for their condensing boilers, which are of the same model and year (from 2005) as those in the building under study.

Building 1 (L1-007_017) - I.T.C. SRAFFA: boiler efficiency is 79%.

Building 2 (L1-007_019) - I.T.I.S. AMALDI: boiler efficiency is 78%.

Given the shared specifications, it is reasonable to estimate that Building 3 (L1-007_021) – L.S. "AMALDI," used in this case study, also has condensing boilers with an efficiency of approximately 79%.

Regulatory Framework and Financial Incentives

Legislative Decree 192/2005 mentions that condensing boilers must meet a minimum seasonal energy efficiency standard for heating, often above 90%, depending on specific building applications. This efficiency is measured under conditions that reflect average seasonal usage.

Another decree that will be followed for replacing condensing boilers implement the EU's Energy Performance of Buildings Directive (EPBD) in Italy, setting minimum energy efficiency standards for heating systems and promoting energy-efficient upgrades.

UNI/TS 11300-2 is an Italian technical standard that provides guidelines for calculating the energy performance of heating systems in buildings, focusing specifically on space heating and domestic hot water production. This standard, part of the broader UNI/TS 11300 series, is critical for compliance with Italy's energy efficiency regulations and for evaluating the energy consumption of buildings in line with the European Energy Performance of Buildings Directive (EPBD).

As outlined by Prezzario (2024), costs for condensing are provided per unit and the cost for a floor-standing condensing boiler with a fire power of 500 kW is €35,332.15.

The current condensing boilers have an estimated seasonal global efficiency of 79%, which falls short of the standard. Legislative Decree 192/2005 mandates a minimum efficiency of 90% for heat generators, suggesting that replacing these boilers is necessary to meet compliance.

Characteristics Of the Condensing Boilers

According to the 2024 (Prezzario) Edition of the Regional Price List for Thermal Systems by Regione Piemonte, there are two primary types of condensing boilers approved for use, meeting the standards established for the region.

- **Wall-mounted Condensing Boilers**: These boilers are suitable for both heating and instant domestic hot water production. They come with electronic ignition, ionization flame control, and integrated control panels. Wall-mounted models vary by power rating and can include additional features like built-in water storage for specific applications.
- **Floor-standing Condensing Boilers**: These models are larger and designed for higher power applications, ranging from 50 kW up to 1,100 kW. Floor-standing boilers are available with electronic controls, climate sensors, and digital thermostats, offering robust solutions for commercial or larger residential settings.

Considering the size of the high school building and the existing condensing boilers, it is decided to used floor standing condensing boiler with 500 kW firebox power.

Technical Information of Condensing Boilers

A floor-standing condensing boiler typically has a lifespan of around 15-20 years, depending on factors such as maintenance, installation quality, and the specific model used. Regular maintenance can help the boiler reach the upper end of this range by minimizing wear and addressing any potential issues early on (How long do boilers last?)

In Italy, condensing boilers are often rated with a star classification system, where the number of stars indicates the energy efficiency level of the boiler. A four-star (****) rating typically reflects that the condensing boiler has achieved high efficiency, often exceeding 90%. A high rating is indicative of the boiler's superior energy performance, which is important for both reducing operational costs and complying with regulations like those in Legislative Decree 192/2005

While some components of condensing boilers can be recycled, the main contributors to environmental impacts from production to landfill are steel, stainless-steel materials along with printed wiring boards. (Vignali, 2016)

Since the building’s condensing boilers were installed in 2005, they are nearing the end of their operational lifespan. Replacing them with four-star (****) rating condensing boilers is justified by their aging technical characteristics, which likely limit performance and efficiency.

Application of Edilclima Software

To achieve results that meet Italian regulations for retrofitting school buildings, the BIM software Revit will be integrated with Edilclima software. Edilclima enables compliance with UNI/TS 11300-2 technical standards for heating systems, providing accurate evaluations of building performance aligned with local laws and standards.

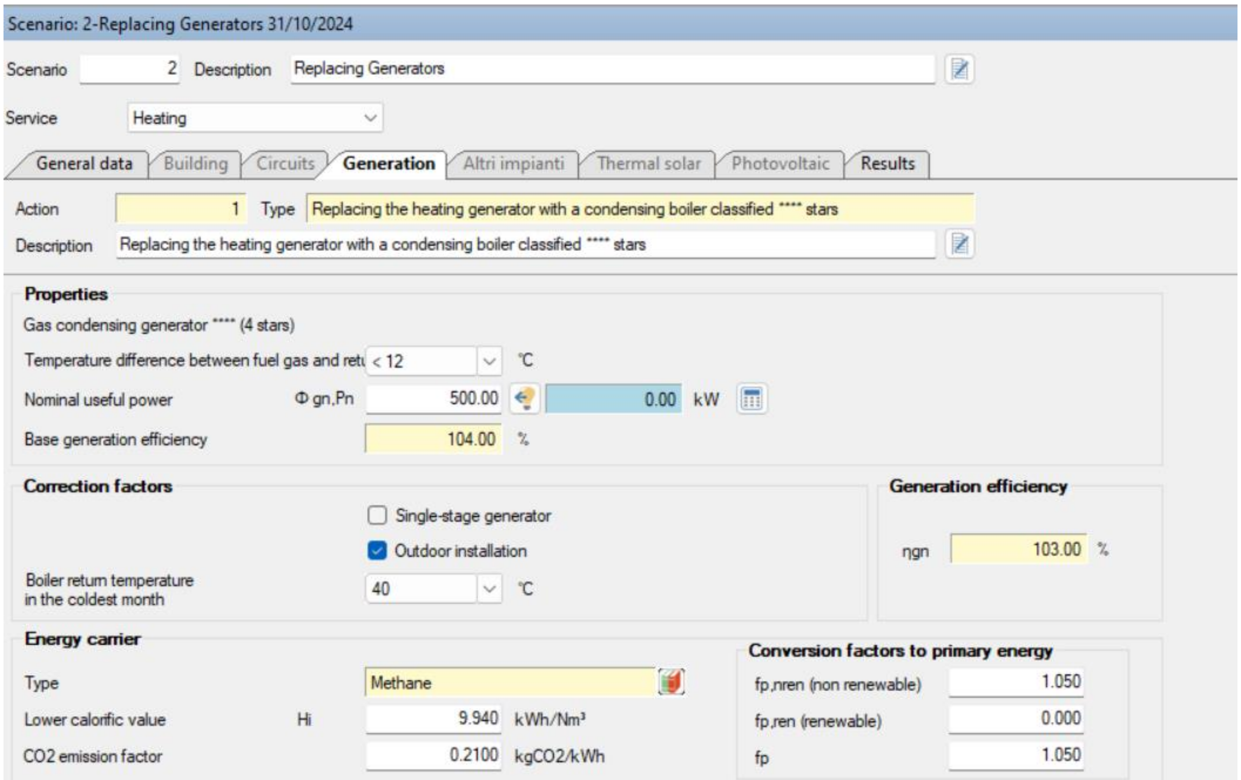
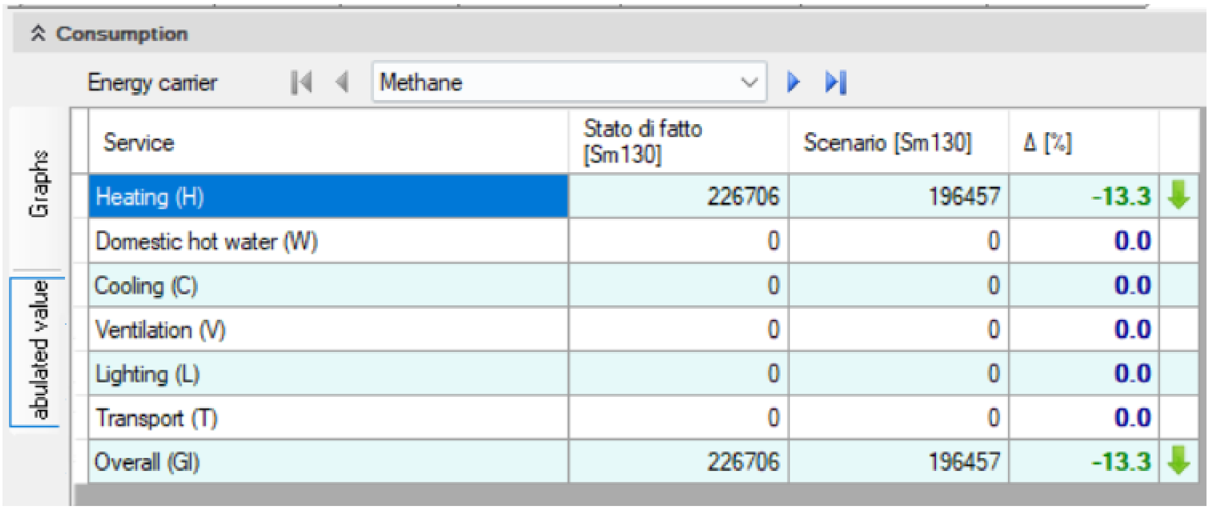


Figure 65 Edilclima EC700 Scenario for Replacing Existing Condensing Boilers

Following the evaluation of the current condensing boilers, the decision was made to replace them with high-efficiency, four-star-rated condensing boilers. To ensure the most accurate assessment, detailed information on the nominal useful power, installation placement, and energy type properties was entered. This data allows for precise calculation and optimization of boiler performance.

Results



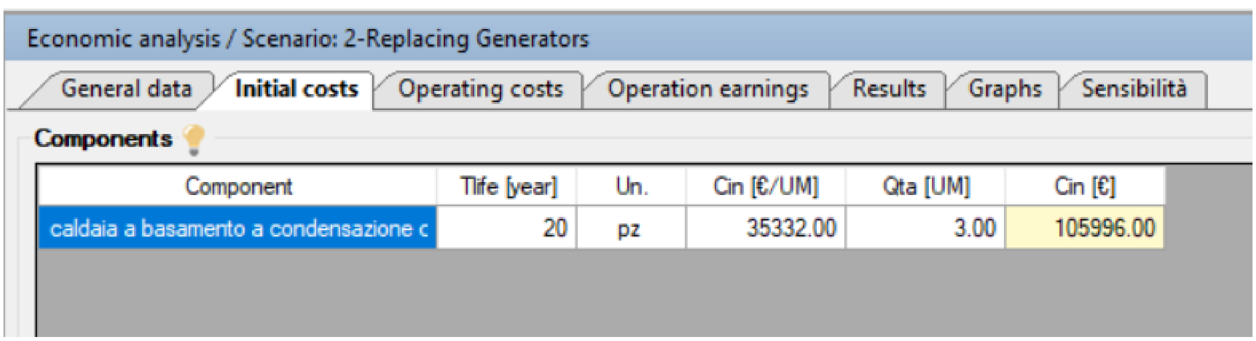
Consumption

Energy carrier: Methane

Service	Stato di fatto [Sm130]	Scenario [Sm130]	Δ [%]
Heating (H)	226706	196457	-13.3
Domestic hot water (W)	0	0	0.0
Cooling (C)	0	0	0.0
Ventilation (V)	0	0	0.0
Lighting (L)	0	0	0.0
Transport (T)	0	0	0.0
Overall (Gl)	226706	196457	-13.3

Figure 66 Comparative Result of Energy demand for Replacing Condensing Boilers

A comparative scenario was created by simulating the energy performance of the building before and after the replacement of the condensing boilers. The results demonstrate a decrease in heating demand and the energy savings resulting from the replacement. Specifically, the non-renewable energy performance (EPgl, nren) using methane as the energy carrier for the existing building was recorded at 226,706 kWh/m² per year. After replacing the condensing boilers, this amount dropped to 196,457 kWh/m² per year, leading to an overall energy demand reduction of approximately 13.3%.



Economic analysis / Scenario: 2-Replacing Generators

General data | Initial costs | Operating costs | Operation earnings | Results | Graphs | Sensibilità

Components

Component	Tlife [year]	Un.	Cin [€/UM]	Qta [UM]	Cin [€]
caldaia a basamento a condensazione c	20	pz	35332.00	3.00	105996.00

Figure 67 Initial Costs for Replacing Condensing Boilers Approach

According to Prezzario (2024), the unit price for a single 500 kW condensing boiler is €35,332, which is applied to all three existing boilers. The analysis considers a financing period of 20 years with a 1% interest rate. Maintenance and insurance costs are estimated at 5% of the total system cost, while management expenses are calculated at 0.5%. Since prices can differ based on the region and location of the building, a 5% inflation rate for non-renewable energy sources is applied, as recommended by Testi et al. (2017).

Results			
Total initial cost	Ctot,in	105996.00	€
Deductible total initial cost	Ctot,in,det	0.00	€
Present values of total operating costs	Ces,tot,pv	3329.57	€
Present value of total operation earnings	Res,tot,pv	1052683.70	€
Operation net present value	NPVop	943358.13	€
Global cost	CG	6934563.46	€
Global cost (UNI/TS 11819)	CG 11819	-943358.13	€
Annuity considered in the operation	Top	20	years
Capitalization rate of the action	fpv,op	18.05	
Yearly equivalent of the operation	Aop	52276.49	€
Additional economical indicators			
Comparative return time	PB	3	age
True pay-back time of the investment	Tr,eff	1.00	years
Internal return rate	TIR	-	%
Revenue index	IP	8.90	

Figure 68 Economic Evaluation for Replacing Condensing Boilers

The economic assessment reveals that the total initial investment for replacing the condensing boilers is €105,996, leading to a payback period of about 3.0 years (as calculated according to UNI EN 15459). This indicates that after this duration, the savings from lower energy costs will cover the initial costs.

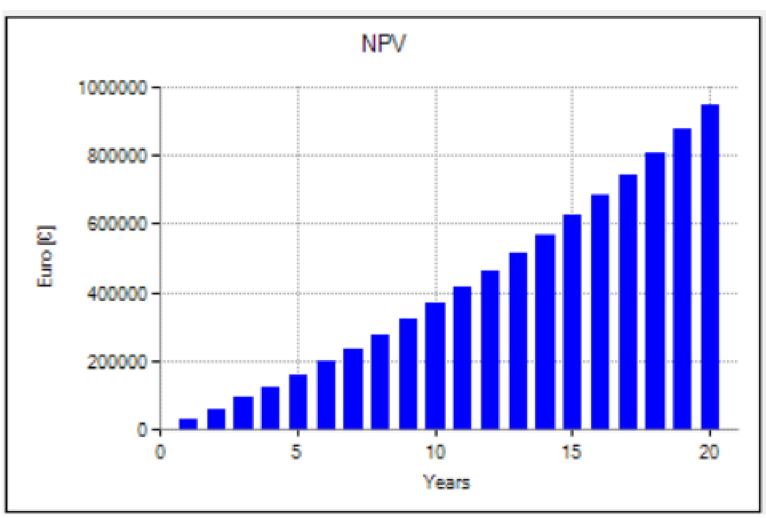


Figure 69 Graph from EC 700 regarding replacing existing condensing boilers.

The graph illustrates the net present value (NPV) of the investment over time. The X-axis indicates time in years, beginning at zero and extending beyond 20 years, representing the period over which the investment's cash flows are monitored. The Y-axis, labeled in thousands of Euros, displays the scale of the cash flows, both negative and positive. The blue bar represents the NPV, which becomes positive after a certain period and continues to increase, reaching €943,368, making this investment approach highly appealing.

Another evaluation involves calculating the CO_2 reduction, which is based on the savings in emissions corresponding to the total energy reduction. With a 13.3% decrease in energy demand, resulting in a total savings of 35,910 kWh, there is a significant reduction in emissions. For instance, using Italy's average emissions of 319 g CO_2eq/kWh (Current emissions in Italy, n.d.) and applying the factor of 0.31 kg CO_2 per kWh, the total CO_2 reduction can be calculated as follows:

28,890kWh x 0.31 kg = 11,132 CO_2 is total CO_2 reduction.

To express this on a per-square-meter basis, divide the total reduction by the building's area, resulting in approximately 11.19 kg CO_2/m^2 annually.

Evaluations

Economic evaluation

The total initial investment for replacing the condensing boilers amounts to €105,996, With a payback period of approximately 3.0 years, the project is expected to generate enough savings from reduced energy costs to recover the initial expenditure within a relatively short time frame. The positive net present value (NPV) of €943,368 underscores the attractiveness of this investment.

Sustainable evaluation

Condensing boilers use less fuel to generate the same amount of heat, they produce significantly lower carbon emissions compared to non-condensing models. This helps in reducing the overall carbon footprint of heating systems. Highly efficient condensing boilers results with 13.3% reduction in non-renewable energy sources and resulting 11.19 kg CO_2 emissions reductions annually.

6.2 Design Hypothesis Regarding Insulation

6.2.1 Green Roof Optimization

The first design strategy regarding insulation for the Amaldi School complex in Orbassano emphasizes the incorporation of green roofs into the existing structures. This approach seeks to minimize the environmental footprint of the buildings and positions the L.S. Amaldi as a benchmark for future sustainable architecture projects, enhancing both energy efficiency and ecological performance.

The integration of Green Roofs has been chosen as an approach due to its numerous benefits. Such as enhancing building insulation, reducing energy consumption for heating in winter and cooling in summer, which can lead to lower energy bills. Another benefit of green roof integration is Stormwater Management. These roofs absorb rainwater, reducing runoff and minimizing the risk of urban flooding. They allow for better management of stormwater by slowing down and filtering water before it reaches drainage systems (Green Roofs, n.d.)

By introducing vegetation, green roofs help cool cities, lowering overall temperatures and combating the urban heat island effect, which is much common in densely populated areas. As well as providing habitats for various species, contributing to urban biodiversity. Another aspect of the approach is vegetation on green roofs helps filter pollutants and particulate matter from the air, enhancing overall air quality in urban settings. Lastly it is possible to say that green roofs can improve the aesthetic appeal of buildings and provide space for community gardens or recreational areas, improving the visual appeal of urban landscapes (The Top 10 Social and Environmental Benefits of Living Green Roofs in Urban Areas, n.d.)

Regulatory Framework and Financial Incentives

The Ministerial Decree (DM) dated June 26, 2015, establishes the framework for the design, implementation, and upkeep of green roofs in Italy. Its primary objective is to foster sustainable urban development by incorporating vegetation into architectural designs.

The decree includes detailed requirements for the various components of green roofs, such as substrate layers, drainage systems, and waterproofing membranes. It also highlights the ecological advantages these roofs provide, such as enhancing thermal insulation, boosting biodiversity, and improving air quality. Moreover, it underscores the necessity of choosing suitable plant species that can adapt to the local climate while minimizing maintenance efforts.

According to Annex 1, Article 5.2, paragraphs 1a, b, c, and Article 4.2, paragraph 1a, as well as Article 1.4.3, paragraph 2, and Appendix B from decree, for climate zone E—where Orbassano is located—the maximum allowable thermal transmittance (Ulimit) for opaque roof structures is set at 0.26 W/m^2K.

Additionally, the decree highlights the importance of managing periodic thermal transmittance, assessing the risks of mold and interstitial condensation, and evaluating the potential for overheating. These guidelines are for ensuring that green roofs not only contribute to aesthetic and ecological benefits but also maintain energy efficiency and structural integrity.

The **UNI 8627:2019 standard** categorizes roofs based on their geometric characteristics, distinguishing between flat and sloping roofs. The functional classifications are as follows:

- **Horizontal roofs**: These have a slope of less than 1%.
- **Sub-horizontal roofs**: These have a slope ranging from 1% to 5%.
- **Sloping roofs**: These feature a slope greater than 5%.

Green roofs can also be installed on sloping roofs, provided the angle does not exceed 30°.

L.S. Amaldi High School building's roof has 5% of slope therefore it is categorized as sloping roofs.

The **UNI 8089 standard** defines a "roof" as a technological unit that effectively seals the building envelope at the top. Its primary function is to create stable internal conditions—thermo-hygrometric and acoustic—that contribute to overall environmental comfort.

The **UNI 8178 standard** differentiates between continuous and discontinuous roofs. Continuous roofs ensure water tightness through specific technical features, while discontinuous roofs meet this requirement based on their slope, technical components, and geometric configuration.

The green roof design proposal for the L.S. Amaldi High School building will follow the guidelines set out in the Ministerial Decree (DM). This means ensuring that the design meets all necessary requirements for sustainability and energy efficiency. The project will focus on implementing strategies that comply with these regulations, helping to create a green roof that is both functional and up to date.

According to **Prezzario (2024)** in Italy, the installation costs for Extensive Green Roofs (EGR) amount to €54.67 per square meter while for Intensive Green Roofs (IGR) cost €63.48 per square meter. When it comes to the maintenance cost for extensive green roofs (EGRs) is about €2.00 per square meter, while for intensive green roofs (IGRs), it averages nearly €7.00 per square meter (Perini & Rosasco, 2016).

For the L.S. Amaldi High School building green roof design proposal installation and maintenance costs per square meter that are indicated above are going to be considered.

Characteristic of Green Roofs

The **UNI 11235:2015** standard outlines criteria for designing, executing, controlling, and maintaining green roofs. It emphasizes the need to consider the specific climatic conditions, building characteristics, and intended use of the structure. Within this framework, green roofs are categorized into two primary types: **extensive** and **intensive**. Differences between the two are characterized by the soil thickness. While extensive green roofs have 8 to 15 cm soil layer thickness, intensive roofs have 25-30 cm soil layer thickness. This is a simplified distinction because other intermediate solutions exist, known as semi-intensive or semi-extensive.

The choice of vegetation is also related to thickness of the soil layer.

0-5 cm: sedum and lichens.

5-10 cm: perennial lawn grass.

10-20 cm: low-medium perennials and small shrubs.

More than 20 cm: medium-large shrubs.

Next part explores more information regarding the difference between two primary types.

Extensive Green Roofs

Extensive green roofs are designed to be lightweight and require minimal maintenance. They usually feature a shallow substrate layer that is 8 to 15 centimeters thick. Because of their light weight, extensive green roofs typically weigh under 150 kg/m², allowing them to be suitable for several types of buildings without needing major structural modifications (PRESTAZIONI ENERGETICHE DEI TETTI VERDI, 2020).

Figure 70 Extensive Green Roof Example (Setherton, n.d.)

Intensive Green Roof

Intensive green roofs are engineered to accommodate a broader range of plant species and usually necessitate more significant structural reinforcement because of their greater weight - typically over 150 kg/m². and deeper soil layer. These roofs generally feature a substrate thickness of 25 to 50 centimeters or more, facilitating enhanced biodiversity that includes small trees, shrubs, and perennials (PRESTAZIONI ENERGETICHE DEI TETTI VERDI, 2020).

Figure 71 Intensive Green Roof Example (Intensive vs. extensive green roofs, n.d.)

Green roofs have a lifespan of 50 to 100 years, significantly outlasting the typical 15-year lifespan of standard roofs (Vernon et al., 2021). Also, at the end of a green roof's life, disposal methods generally involve partial recycling, partial incineration, and partial landfilling. (Peri et al., 2022)

For the L.S. Amaldi High School building case study, the approach is to investigate the design of extensive green roofs. According to (Cascone et al., 2018), this type of green roof is particularly beneficial for retrofitting existing structures due to its lightweight nature, which significantly reduces the load on the building's structural system.

Technical Information of Green Roofs

According to the Ministerial Decree, a green roof must include several essential layers arranged in a specific order. Those layers are.

1. Vegetation: This layer helps to limit temperature fluctuations. The choice of plants depends on the substrate depth and external climate conditions.

   In Turin, diverse tree and shrub vegetation contributes to the urban ecosystem. Common tree species include various Quercus (oaks), Platanus (plane trees), Tilia (linden trees), Aesculus (horse chestnut), and Robinia (black locust). These trees are valued for their ecological benefits, such as providing shade and habitats for urban wildlife. Shrubbery in the city features species like Ligustrum (privet), often used for hedges due to its dense growth, Buxus (boxwood), and Rosa (roses) (Alberi e arbusti, n.d.).

2. Growing Substrate (or Cultivation Layer): This layer supports the growth of vegetation on the green roof. It is typically made from lightweight materials such as vermiculite or perlite.
3. Filter Layer: This layer separates the growing substrate from the drainage layer, preventing blockages in the lower layers.
4. Drainage Layer: This layer facilitates the removal of excess water from the growing substrate, reducing the load on the building. It is usually made from polyethylene membranes or granular materials like expanded clay.
5. Mechanical Protection Layer: This root barrier protects the underlying layers. Polymer materials are typically used for this purpose.
6. Waterproofing Layer: This protective layer is created using waterproof membranes. It is essential for flat roofs due to the increased difficulty in rainwater drainage.
7. Thermal Insulation: This layer mitigates energy flow through the roof.
8. Vapor Barrier: This layer controls vapor flow through the roof to prevent the risk of interstitial condensation.
9. Slope Layer: This layer prevents water from pooling. The slope typically ranges from 0.5% to 5%, although slopes less than 1.5% can increase the risk of standing water. The roof is divided into sections with different orientations and slopes to facilitate the drainage of rainwater to multiple collection points.
10. Roof Structure: This is the load-bearing structure of the roof.

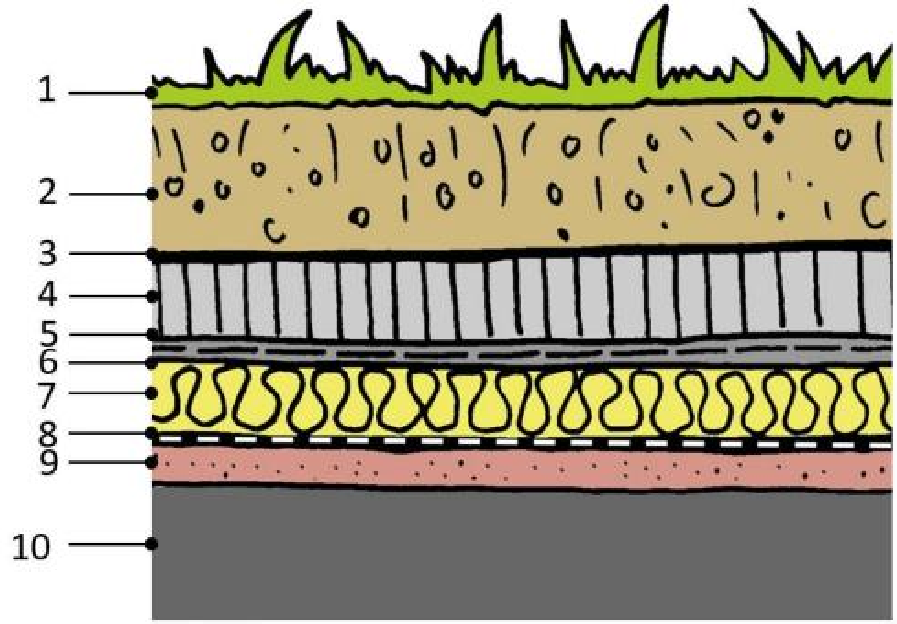


Figure 72 Composition of a green roof (PRESTAZIONI ENERGETICHE DEI TETTI VERDI, 2020)

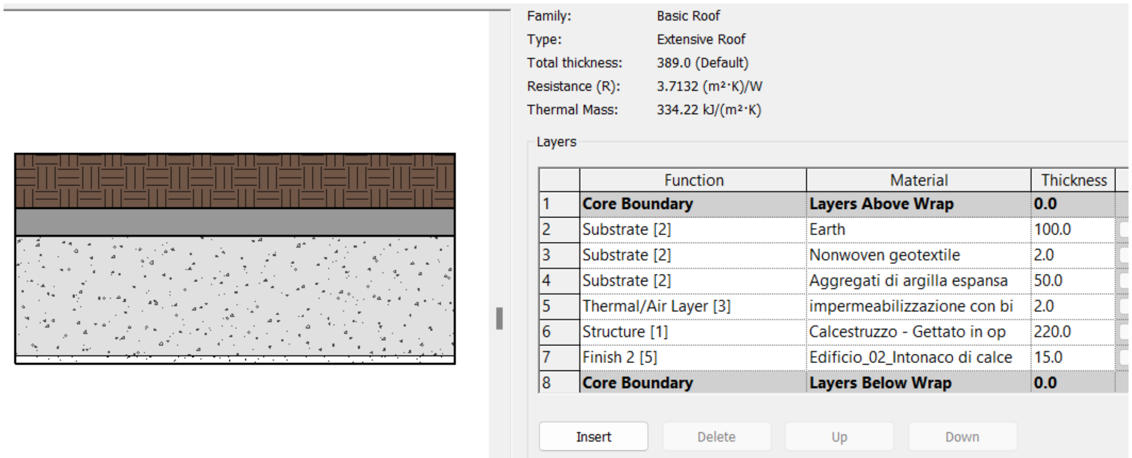
According to the UNI 11235:2015 standard, the proposed design for an extensive green roof consists of the following layers:

1. Existing Structural Support: The current roof, made of reinforced concrete, will be maintained, as modifying the structure would result in significant costs.
2. Waterproofing Membrane: A 2.0 mm thick bituminous membrane is applied to ensure the roof remains waterproof.
3. Drainage Layer: A 5.0 cm layer of lightweight aggregates, such as expanded clay, is included to manage excess water effectively.
4. Filter Layer: A 2.0 mm nonwoven geotextile is used to prevent the loss of soil while allowing water to drain properly.
5. Soil Layer: A 10 cm thick layer made up of organic materials, soil, and aggregates is added to support plant growth.
6. Vegetation Layer: Drought-resistant plants, such as sedums and other succulents, are selected. The thickness of this layer may vary as the plants grow but stays above the growing medium.

Application of Edilclima Software

To ensure compliance with Italian regulations for retrofitting school buildings, the design process will incorporate the use of BIM software Revit alongside Edilclima. This combination will help achieve accurate results in energy efficiency and building performance simulations while adhering to legal requirements.

The first step involves modeling the extensive green roof design in Revit software according to the UNI 11235:2015 standard, ensuring that all design layers and specifications meet the established guidelines.



Family: Basic Roof
Type: Extensive Roof
Total thickness: 389.0 (Default)
Resistance (R): 3.7132 (m²·K)/W
Thermal Mass: 334.22 kJ/(m²·K)

Layers

	Function	Material	Thickness
1	**Core Boundary**	**Layers Above Wrap**	**0.0**
2	Substrate [2]	Earth	100.0
3	Substrate [2]	Nonwoven geotextile	2.0
4	Substrate [2]	Aggregati di argilla espansa	50.0
5	Thermal/Air Layer [3]	impermeabilizzazione con bi	2.0
6	Structure [1]	Calcestruzzo - Gettato in op	220.0
7	Finish 2 [5]	Edificio_02_Intonaco di calce	15.0
8	**Core Boundary**	**Layers Below Wrap**	**0.0**

Figure 73 Screenshot of Extensive Roof on Revit Software

1. **Earth (100.0 mm)**: This is the top layer representing the vegetation support, typically consisting of a soil, or growing medium to sustain plant life. In this case, it is 100 mm thick, which aligns with an extensive green roof's usual soil depth (8-15 cm).

2. **Nonwoven Geotextile (2.0 mm)**: A filter layer that prevents soil from being washed away into the drainage system while allowing water to pass through. It helps with proper drainage and maintaining soil integrity.

3. **Expanded Clay (50.0 mm)**: This is a lightweight aggregate layer (expanded clay in this case) that acts as a drainage layer. It allows excess water to drain efficiently while retaining some moisture for the plants.

4. **Waterproofing Membrane (2.0 mm)**: To prevent water from leaking into the structure below. Bituminous or synthetic membranes are often used for this purpose.

5. **Existing Structure (220.0 mm):** A 220 mm structural layer, which provides strength and support to the roof.

6. **Finishing:** The final 15 mm lime and plaster finish layer, which adds a smooth protective coating to the roof's surface.

The Total thickness of this assembly is 389 mm (or 38.9 cm), which includes all layers with a thermal resistance of 3.71 m²·K/W and U value of 0.24 W/m²K.

After creating the extensive green roof design for the L.S. Amaldi High School building in Revit, the model was transferred to the Edilclima software using the EC770 Plug-in. This integration enables the assessment of how the changes to the roof influence energy efficiency. Like the existing building, all relevant data were entered, including climatic conditions, system specifications, heating and cooling systems, mechanical ventilation, lighting, hot water production, and energy sources, ensuring an inclusive analysis based on consistent information.

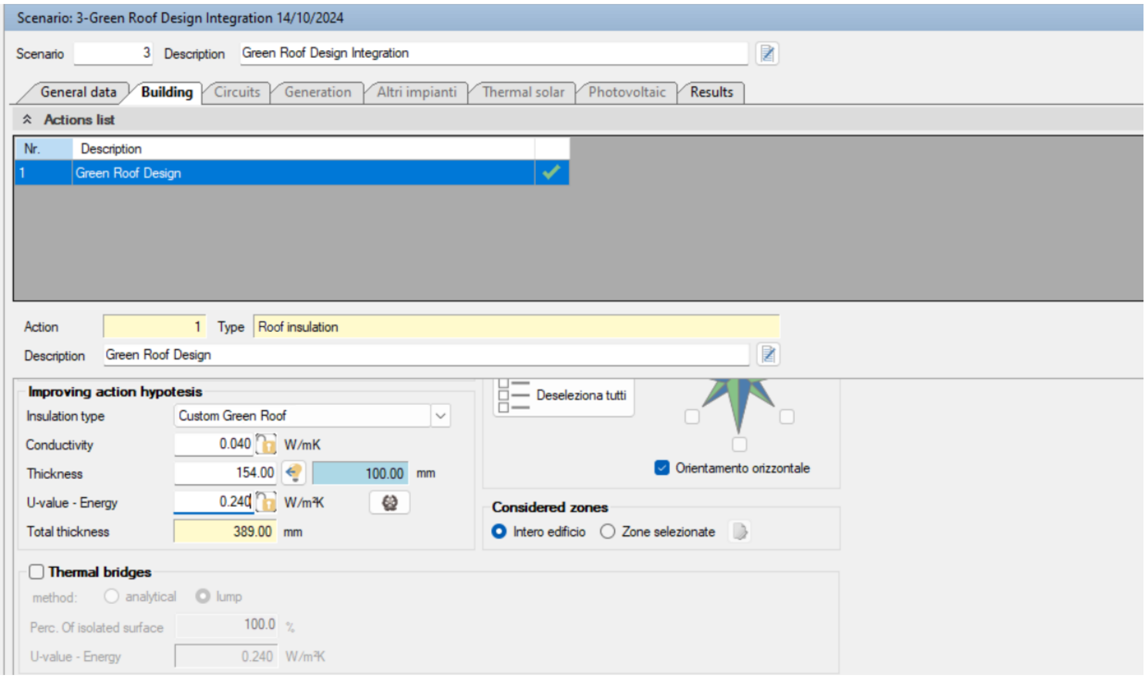


Figure 74 Edilclima EC700 Scenario for Green Roof Integration

Since Edilclima does not provide a specific calculation method for green roof design, a scenario was created that treats the green roof as roof insulation. The values for thermal conductivity, U-value, and thickness of the extensive green roof were manually input according to the guidelines set by the Ministerial Decree and the UNI 11235:2015 standard. Thermal transmittance (Ulimit) for opaque roof structures has been set at 0.24 W/m²K.

Results

Service	Stato di fatto [Sm130]	Scenario [Sm130]	Δ [%]
Heating (H)	226706	203129	-10.4
Domestic hot water (W)	0	0	0.0
Cooling (C)	0	0	0.0
Ventilation (V)	0	0	0.0
Lighting (L)	0	0	0.0
Transport (T)	0	0	0.0
Overall (Gl)	226706	203129	-10.4

Figure 75 Comparative Result of Energy demand for Green Roof Integration Scenario

A comparative scenario was established by simulating the energy performance of the building both before and after the installation of the extensive green roof. The results indicate a reduction in heating demand, allowing for precise quantification of the energy savings associated with the roof. Specifically, the non-renewable energy performance (EPgl, nren) for the existing building was measured at 226,706 kWh/m² per year, but with the implementation of the green roof, this figure decreased to 203,129 kWh/m² per year. This change results in an overall energy demand reduction of approximately 10.4%.

Economic analysis / Scenario: 3-Green Roof Design Integration

General data | **Initial costs** | Operating costs | Operation earnings | Results | Graphs | Sensibilità

Components

Component	Tlife [year]	Un.	Cin [€/UM]	Qta [UM]	Cin [€]
Extensive Green Roof	40	m²	54.67	2040.00	111526.80

Figure 76 Initial Costs of Green Roof Integration

The initial cost of €54.67 per square meter was recorded, as referenced by Prezzario (2024). The analysis is based on a financing period of 20 years with a 1% interest rate. Maintenance and insurance costs are assumed to be 5% of the total system cost, while management costs are calculated at 0.5%. Given that prices may vary depending on the region and location of the building, a 5% inflation rate for non-renewable energy sources is applied, as suggested by Testi et al. (2017).

Results

Total initial cost	Ctot,in	111526.80	€
Deductible total initial cost	Ctot,in,det	0.00	€
Present values of total operating costs	Ces,tot,pv	68830.21	€
Present value of total operation earnings	Res,tot,pv	831463.47	€
Operation net present value	NPVop	651106.45	€
Global cost	CG	7226815.14	€
Global cost (UNI/TS 11819)	CG 11819	-651106.45	€
Annuity considered in the operation	Top	20	years
Capitalization rate of the action	fpv,op	18.05	
Yearly equivalent of the operation	Aop	36081.27	€

Additional economical indicators

Comparative return time	PB	5	age
True pay-back time of the investment	Tr,eff	5.00	years
Internal return rate	TIR	-	%
Revenue index	IP	5.84	

Figure 77 Economic Evaluation of Green Roofs

The economic analysis reveals that the total initial investment required for the green roof design is €111,526, resulting in an estimated payback period of around 5 years. After this timeframe, the savings accrued from decreased energy costs will compensate for the initial investment. Furthermore, implementing the green roof design has enhanced the building's energy classification, indicating improved energy efficiency.

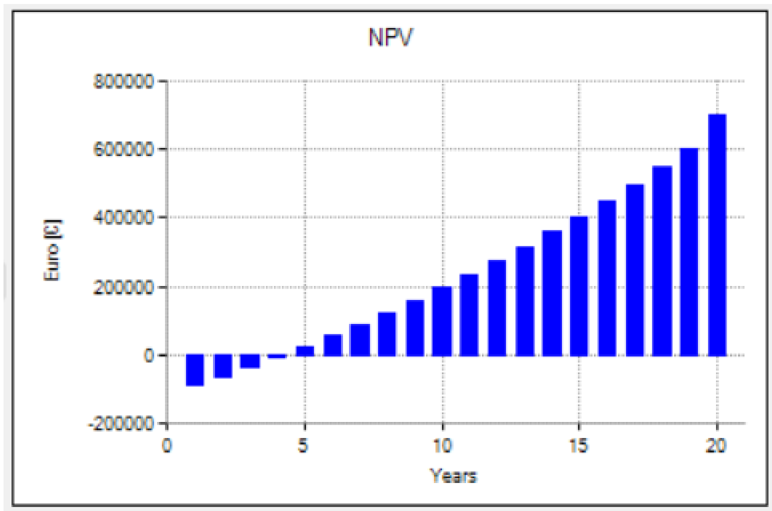


Figure 78 Graph from EC 700 regarding the investment of Green Roofs

The graph illustrates the net present value (NPV) of an investment over time and shows that around year 5 cash flow turns positive. The blue bar indicates the NPV, which turns positive after a certain duration and continues to increase. This growth signifies that the present value of future cash inflows surpasses the initial investment costs. A positive NPV reflects that the investment is financially sound and likely to be profitable in the long run.

Another result that can be calculated is regarding CO_2 reduction. Green Roofs can be part of CO_2 reduction both directly and indirectly. Direct reduction occurs due to vegetation that's been used for the GR when absorbed from atmosphere and indirect reduction can also happen due to energy saving according to thermal properties. (Tan et al., 2023) According to Heusinger and Weber (2017) the annual CO_2 reduction per square meter of the extensive green roof studied was 85 g C. With this reference it is possible to calculate the annual CO_2 reduction for extensive green roof design.

85 g C x 2040 square meter = 171.3 kg of CO_2 emissions are avoided annually.

Evaluations

Economic Evaluation

The proposed green roof design, with a payback period of 5 years, is financially viable, offering not just a recovery of the initial investment but also the potential for long-term financial benefits. This investment aligns with the increasing recognition of the economic advantages associated with green roofs, which can lead to significant energy savings and improved property value over time.

While extensive green roofs require lower maintenance compared to traditional roofing systems, it is crucial to consider ongoing operational costs in comprehensive long-term financial planning. Regular maintenance, while typically less costly, should still be budgeted to ensure the roof's durability and functionality.

Sustainable Evaluation

Green roofs enhance urban biodiversity by creating habitats for various species, aid in stormwater management by absorbing and retaining rainwater, reducing runoff and the risk of flooding and improve air quality by filtering pollutants and particulate matter from the air, resulting in indirect economic benefits through enhanced community well-being. Calculations indicate that they can reduce CO_2 emissions by 171 kg annually. This reduction occurs both directly and indirectly due to their absorption and insulation properties, making green roof design an appealing option.

It is important to note that the plants used in green roofs should be selected based on the specific climate and urban habitat conditions.

Other Evaluations

Before installing a green roof, it is essential to assess the existing roof to ensure it can bear the extra weight of soil and other materials. In some cases, roofs may need reinforcement to effectively support the green roof system, which can also lead to additional costs.

6.2.2 Existing Roof's Insulation with Expanded Polystyrene Insulation

Another design approach for the L.S. Amaldi in Orbassano focuses on insulating the existing roof structures. This approach is intended to enhance thermal efficiency, reduce energy consumption, and lower carbon emissions.

Roof insulation with EPS has been chosen as an alternative due to its many benefits.

Roof insulation helps reduce thermal bridges, which are a major cause of heat dispersion in buildings. A significant amount of heat is lost through the roof. Insulating the roof prevents the formation of interstitial condensation, which can lead to mold and mildew growth on ceilings and walls. Since the roof is fully exposed to rain, it is more prone to moisture issues compared to perimeter walls. Insulation helps to solve these problems. Proper roof insulation enhances the overall thermal comfort of the building by maintaining consistent indoor temperatures and controlling humidity. Another aspect of roof insulation is by reducing unnecessary energy consumption, roof insulation contributes to environmental sustainability and lowers the building's carbon footprint. (Coibentazione tetto: tecniche, costi e materiali di questo sistema di isolamento termico di tetto, n.d.)

Roof insulation significantly reduces energy loss, making heating and cooling systems more efficient, leading to energy savings. When compared to an identical building roof without insulation, insulating layers like polystyrene or polyurethane can reduce the load by more than 50% (Azmi & Ibrahim, 2020)

Regulatory Framework and Financial Incentives

As previously mentioned, the June 26, 2015, decree highlights the importance of efficient design and construction methods while outlining minimum requirements for energy performance in buildings. To improve sustainability and energy efficiency, it establishes criteria for a variety of building components, including roofing.

As was mentioned in the previous scenario, the maximum permissible thermal transmittance (Ulimit) for opaque roof structures is set at 0.26 W/m²K for climate zone E at the ministerial decree, which is where Orbassano is located, in accordance with Annex 1, Article 5.2, paragraphs 1a, b, c, and Article 4.2, paragraph 1a, as well as Article 1.4.3, paragraph 2, and Appendix B.

To differentiate between flat and sloping roofs, the UNI 8627:2019 standard classifies roofs according to their geometric properties. The following are the functional classifications:

- Roofs that are horizontal have a slope of less than one percent.
- The slope of sub-horizontal roofs can range from 1% to 5%.
- Sloping roofs: These have a slope of more than five percent.

L.S. Amaldi High School building's roof is classified as a sloping roof because it has a 5% slope.

A "roof" is a technological item that successfully closes the building envelope at the top, according to the **UNI 8089 standard**. Its main purpose is to provide steady acoustic and thermo-hygrometric interior conditions that enhance overall environmental comfort.
Roofs can be classified as continuous or discontinuous according to the **UNI 8178 standard**. While discontinuous roofs satisfy these criteria due to their slope, technical elements, and geometric configuration, continuous roofs guarantee water tightness through technical features.

The proposal to insulate the existing roof of the L.S. Amaldi High School building will adhere to the Ministerial Decree (DM) criteria. This includes ensuring that the design meets all the requirements for sustainability and energy efficiency. The project will concentrate on applying techniques that comply with these rules, resulting in an insulated roof that is both functional and up to date.
The order also emphasizes the significance of regulating periodic thermal transmittance, reviewing the dangers of mold and interstitial moisture, and examining the possibility of overheating.

There are two reference standards for roof insulation products:
Construction Products Regulation (EU) No. 305/2011: construction materials must be CE-marked and meet the legal minimum safety standards for fire resistance, hygienic practices, and safety;
Building materials must adhere to the CAM Decree's (Minimum Environmental Criteria) sustainability standards throughout the duration of their life cycle. According to CAM guidelines, EPS (Expanded Polystyrene) insulation materials must contain at least 15% cumulative recycled, recovered, or by-product content by weight, with a minimum of 10% specifically from recycled material.

According to Prezzario (2024) different insulation material's cost per square meter or for cubic meter are indicated. According to the document prices for the roof insulation materials have been indicated below.

Polystyrene Expanded Panels (Polistirene Espanso) 35 Kg/m³

- 10 mm thickness: €15.39 per square meter
- 20 mm thickness: €15.48 per square meter
- 30 mm thickness: €17.95 per square meter
- 40 mm thickness: €20.91 per square meter

These materials can cater to thermal insulation needs with varying thickness and density options. For the L.S. Amaldi High School building roof insulation design proposal costs per square meter that are indicated above are going to be considered.

Characteristic of Roof Insulation

Enhancing thermal insulation in buildings is one of the most effective methods for achieving energy savings by minimizing heat loss or gain through building envelopes. However, many traditional construction materials lack adequate insulation properties. To address this, a variety of additional insulation materials—such as solid boards, panels, and coils—are increasingly utilized in areas like exterior walls, roofs, floors, and doors. Insulation materials can be categorized into four types based on their raw materials:

1. Mineral-based: Includes rock wool, glass wool, expanded perlite, and vermiculite.

2. Petrochemical: Comprises materials like polystyrene, polyurethane, and polyethylene.

3. Plant-based: Utilizes agricultural and forestry waste, such as straw, rice husks, and wood shavings.

4. Metal-based: Features materials like metal reflective films, though their use is limited and more expensive than other options. (Liu et al., 2017)

When it comes to insulation on roofs, primary types of roof insulation can be listed as;

- Wood Fiber: Composed of natural fibers, it is durable, has decent strength, and is easy to cut. However, it is unstable, can deteriorate when exposed to moisture, and has poor fire resistance.
- Perlite: A combination of volcanic glass and organic fibers, it is fire-resistant, stable, and strong but can become fragile and deteriorate upon moisture exposure.
- Polyurethane: Known for its high performance, it blocks air infiltration and is heat-resistant but may produce condensates.
- Polyisocyanurate: This insulation has a closed-cell foam core and remains lightweight, strong, and fire-resistant, although its production may contribute to global warming.
- Polystyrene: Available in expanded and extruded forms, it is stable, lightweight, and inexpensive, but has poor fire resistance and emits toxic substances when combusted.
- Cellular Glass: Made from crushed glass and a foaming agent, it is stable with low water absorption and good strength but is expensive and brittle.
- Gypsum Board: Non-combustible and water-resistant, it offers high moisture resistance and excellent wind uplift but is heavy and challenging to work with (What Are the Types of Roofing Insulation?, n.d.).

EPS can last for the entire predicted service life of 50 years without needing replacement or additional maintenance adjustments due to routine maintenance on waterproofing layers does not require replacing the EPS itself (Gomes et al., 2020). However, EPS is not biodegradable, and improper disposal can lead to environmental challenges. Incinerating EPS can release harmful substances, and if sent to landfills, it may break down into microplastics, contributing to environmental pollution. Therefore, careful consideration of the end-of-life properties of EPS is essential for sustainable practices. ((di Gregorio, 2021)

EPS is often used as insulation in roofs, floors, and walls but is not typically designed to be a walkable surface. If walking on EPS is necessary, such as for maintenance, a supportive structure or surface should be installed over the panels. (Can you walk on EPS insulation?, n.d.)

For the L.S. Amaldi High School building case study, the approach involves using polystyrene insulation materials because of their stability, cost-effectiveness, and significant ability to reduce heating and cooling demands.

Technical Information of Roof Insulation

According to the Ministerial Decree, specific considerations for existing buildings undergoing major renovations must be taken and must include several essential layers arranged in a specific order. Those layers are indicated below;

1. External Waterproofing Layer (Roof Covering): This is the top layer, ensuring protection from rain, snow, and wind. It could be made of materials like tiles or membranes that are resistant to weather.
2. Thermal Insulation Layer: Insulation materials like polystyrene, wood fiber, or polyurethane should be applied here. The thickness depends on energy efficiency standards.
3. Vapor Barrier: This is placed below the insulation to prevent moisture from warm indoor air from penetrating the insulation and causing condensation.
4. Air Gap (Optional, for Ventilated Roofs): This gap between the insulation and the structural support helps with air circulation, removing moisture and improving the roof's thermal performance.
5. Structural Support Layer: The existing roof structure, typically made of wood, concrete, or steel, which supports the insulation and other layers.

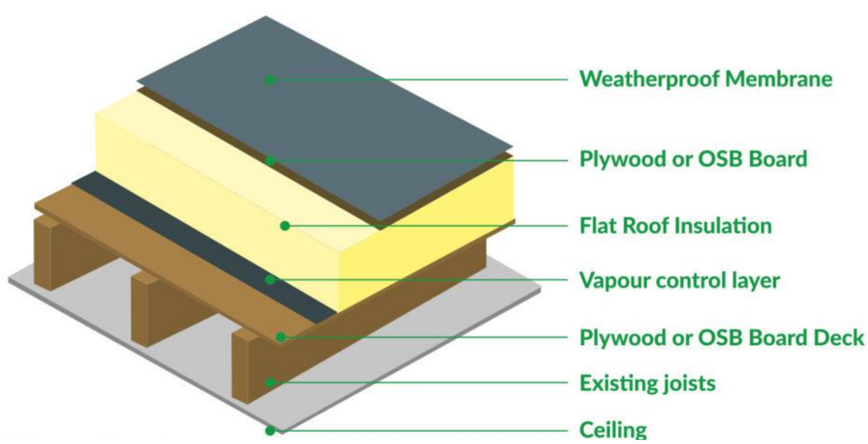


Figure 79 Composition of an insulated roof (Flat Roof Insulation, n.d.)

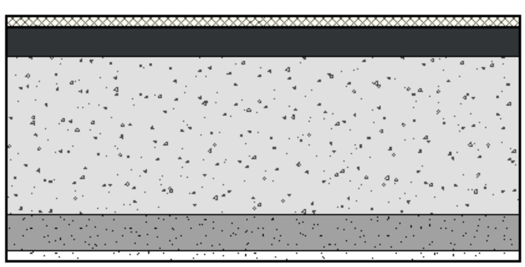
According to Ministerial Decree, the proposed design for an insulated roof consists of the following layers:

1. Existing Roof Layers (Structural Support): The current roof, made of reinforced concrete, will be maintained, as modifying the structure would result in significant costs.
2. Vapor Barrier: A 15mm vapor barrier below the insulation should be added to prevent moisture from the interior from entering the insulation layer, avoiding condensation issues that could lead to mold or degradation of materials.
3. Thermal Insulation Layer (Polystyrene): Below the waterproofing layer, added a layer of Polystyrene (EPS) for insulation. The thickness of this insulation complies with Italian energy efficiency standards and it's 40mm to ensure optimal thermal performance.
4. External Waterproofing Layer (Roof Covering): The top layer, as indicated in the existing structure, remains the same material or is updated to use weather-resistant materials such as tiles or a waterproof membrane. This layer will protect the insulation and internal layers from weather exposure.

Application of Edilclima Software

Like previous approaches, the design process will incorporate the BIM program Revit with Edilclima in order comply to Italian laws for improving school buildings. This strategy will ensure compliance with legal requirements by enabling accurate simulations of building performance and energy efficiency.

Starting with using Revit to model an insulated roof first, make sure that all design layers and specifications comply to the specified standards mentioned in previous steps.



Family: Basic Roof
Type: Insulated Roof
Total thickness: 342.0 (Default)
Resistance (R): 3.3815 (m²·K)/W
Thermal Mass: 323.53 kJ/(m²·K)

Layers

	Function	Material	Thickness
1	**Core Boundary**	**Layers Above Wrap**	**0.0**
2	Finish 1 [4]	Piastrelle in Ceramica	15.0
3	Finish 2 [5]	impermeabilizzazione	2.0
4	Thermal/Air Layer [3]	Polystyrene	40.0
5	Substrate [2]	Calcestruzzo - Gettato	220.0
6	Substrate [2]	Sottofondo di cement	50.0
7	Finish 2 [5]	Edificio_02_Intonaco d	15.0
8	**Core Boundary**	**Layers Below Wrap**	**0.0**

Insert Delete Up Down

Figure 80 Screenshot of Insulated Roof with EPS on Revit Software

1. **Ceramic Tiles (15mm):** This is the finishing roof layer, providing weather resistance and aesthetic appeal.
2. **Bituminous Waterproofing Layer (2mm):** Provides waterproofing to protect the roof from moisture infiltration.

3. **Polystyrene Insulation (40 mm)** Insulates the roof, reducing heat transfer and improving energy efficiency. This thickness is suitable for achieving good thermal performance**.**
4. **Existing Structure (220.0 mm):** A 220 mm structural layer, which provides strength and support to the roof.
5. **Finishing:** The final 15 mm lime and plaster finish layer, which adds a smooth protective coating to the roof's surface.

The Total thickness of this assembly is 342 mm (or 34.2 cm), which includes all layers with a thermal resistance of 3.38 m²·K/W and U value of 0.24 W/m²K.

After creating the insulated roof design for the L.S. Amaldi High School building in Revit, the model was transferred to the Edilclima software using the EC770 Plug-in. This integration makes it possible to evaluate the impact of roof modifications on energy efficiency. To compare the improvements, all relevant information has been entered just as the existing building. Such as climate conditions, system specifications, heating and cooling systems, mechanical ventilation, lighting, hot water production, and energy sources, just like in the present building.

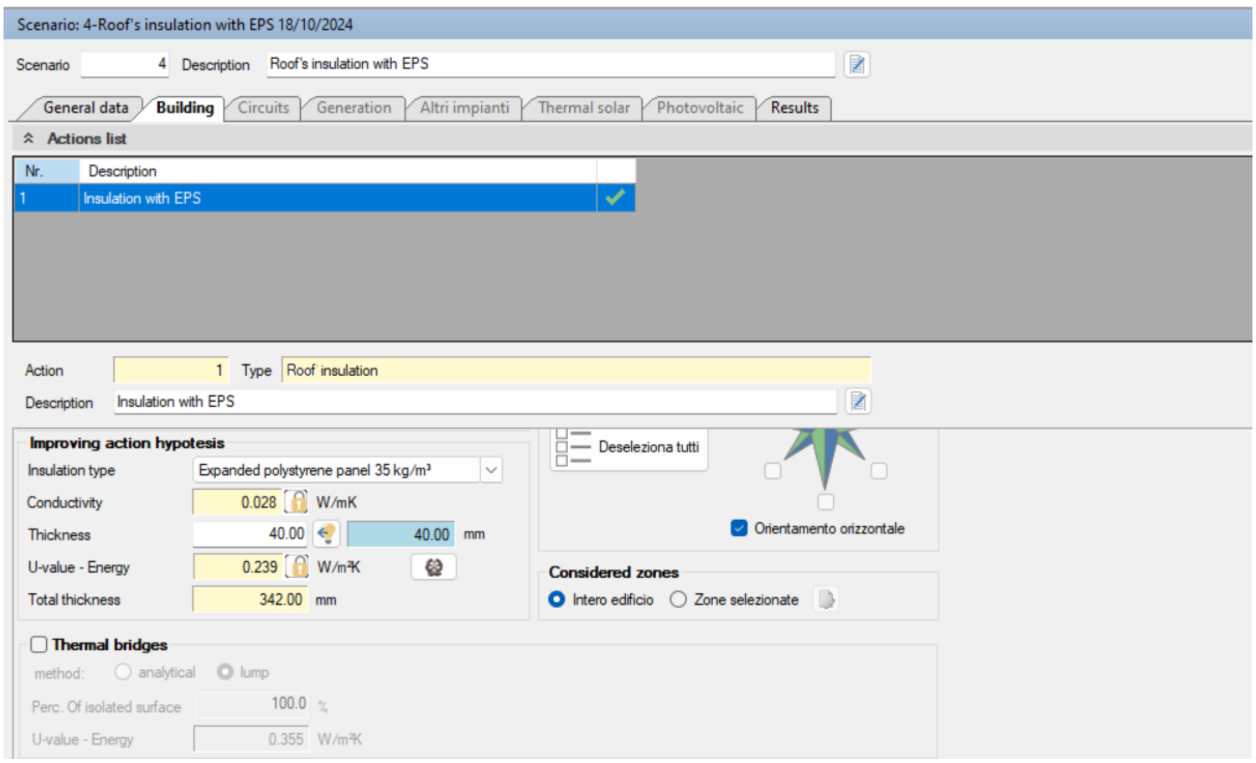


Figure 81 Edilclima EC700 Scenario for Roof Insulation with EPS

A scenario was created that shows roof insulation. The values for thermal conductivity, U-value, and thickness of the EPS roof insulation were manually input according to the guidelines set by the Ministerial Decree and the UNI 11235:2015 standard. Thermal transmittance (Ulimit) for opaque roof structures has been set at 0.239 W/m²K.

Results

Service	Stato di fatto [Sm130]	Scenario [Sm130]	Δ [%]
Heating (H)	226706	202489	-10.7
Domestic hot water (W)	0	0	0.0
Cooling (C)	0	0	0.0
Ventilation (V)	0	0	0.0
Lighting (L)	0	0	0.0
Transport (T)	0	0	0.0
Overall (Gl)	226706	202489	-10.7

Figure 82 Comparative Result of Energy demand for EPS Roof Insulation Scenario

A comparative scenario was created by simulating the building's energy performance both before and after adding insulation layers to the roof. The findings reveal a decrease in heating demand, enabling a precise calculation of the energy savings linked to the roof installation. Specifically, the non-renewable energy performance (EPgl, nren) for the existing building was recorded at 226,706 kWh/m² annually, but after implementing the EPS material, this value dropped to 202,489 kWh/m² per year. This change leads to an overall reduction in energy demand of about 10.7%.

Economic analysis / Scenario: 4-Roof's insulation with EPS

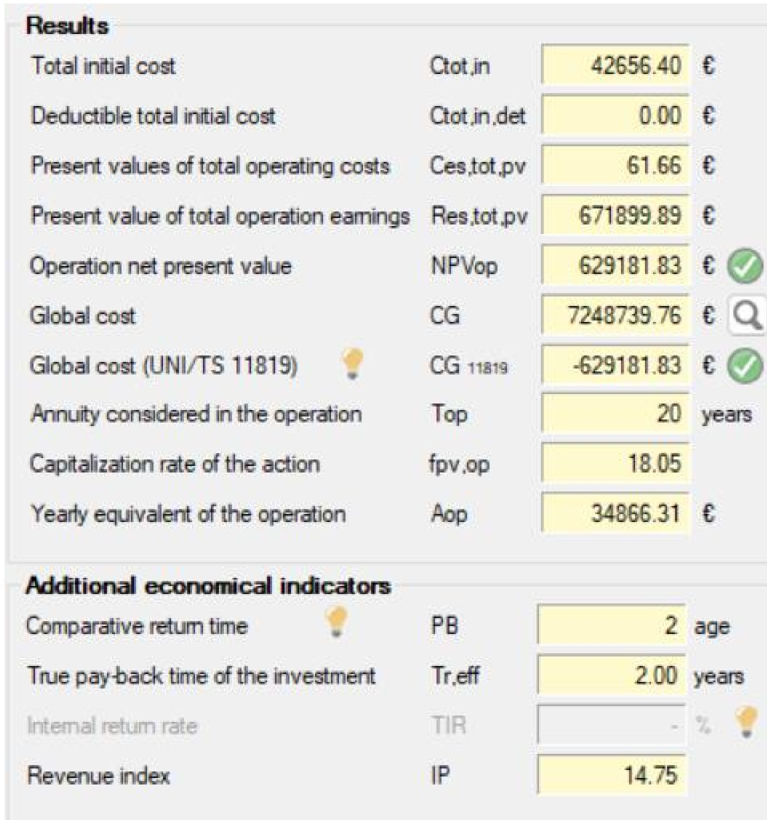
General data | **Initial costs** | Operating costs | Operation earnings | Results | Graphs | Sensibilità

Components

Component	Tlife [year]	Un.	Cin [€/UM]	Qta [UM]	Cin [€]
Pannello polistirene espanso 35 kg/m³ - s	40	m²	20.91	2040.00	42656.40

Figure 83 Initial Costs of insulation with EPS

For the EPS material, the initial cost of €20.91 per square meter was recorded, as referenced by Prezzario (2024). The analysis is based on a financing period of 20 years with a 1% interest rate. Maintenance and insurance costs are assumed to be 5% of the total system cost, while management costs are calculated at 0.5%. Given that prices may vary depending on the region and location of the building, a 5% inflation rate for non-renewable energy sources is applied, as suggested by Testi et al. (2017).



Results

Total initial cost	Ctot,in	42656.40	€
Deductible total initial cost	Ctot,in,det	0.00	€
Present values of total operating costs	Ces,tot,pv	61.66	€
Present value of total operation earnings	Res,tot,pv	671899.89	€
Operation net present value	NPVop	629181.83	€
Global cost	CG	7248739.76	€
Global cost (UNI/TS 11819)	CG 11819	-629181.83	€
Annuity considered in the operation	Top	20	years
Capitalization rate of the action	fpv,op	18.05	
Yearly equivalent of the operation	Aop	34866.31	€

Additional economical indicators

Comparative return time	PB	2	age
True pay-back time of the investment	Tr,eff	2.00	years
Internal return rate	TIR	-	%
Revenue index	IP	14.75	

Figure 84 Economic Evaluation of Roof Insulation with EPS

The economic analysis indicates that the total initial investment needed for the roof insulation amounts to €42,656, with an estimated payback period of 2 years. After this period, the savings from reduced energy costs will offset the initial investment.

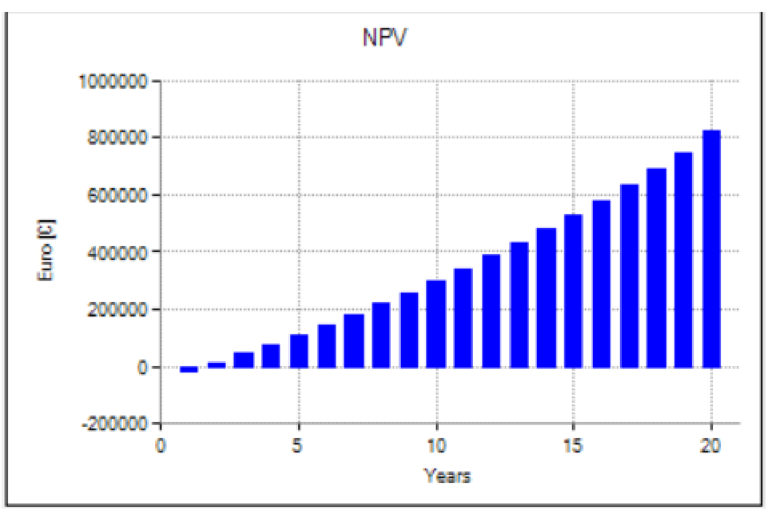


Figure 85 Graph from EC 700 regarding the Roof's insulation with EPS

The graph depicts the net present value (NPV) of an investment over time, indicating that cash flow becomes positive around the second year. The blue bar represents the NPV, which transitions to a positive value after a specific period and continues to rise. This upward trend indicates that the present value of future cash inflows exceeds the initial investment costs. A positive NPV signifies that the investment is financially viable and is expected to be profitable over the long term.

Another result for evaluating is calculating CO_2 reduction. It involves calculating emissions savings based on total energy reduction. Given the calculation of total energy savings, it's possible to quantify the CO_2 reduction achieved. For example, with Italy's average emissions of 319 g CO_2eq/kWh (Current emissions in Italy, n.d.), the 10.7% decrease in energy demand, equating to a total of 28,890 kWh saved, leads to a substantial reduction in emissions. Applying the factor of 0.31 kg CO_2 per kWh, the total CO_2 reduction is calculated as:

28,890kWh x 0.31 kg = 8,955.9kg CO_2 is total CO_2 reduction.

To express this on a per-square-meter basis, divide the total reduction by the building's area, resulting in approximately 9.0 kg CO_2/m^2 annually.

Evaluation

Economic Evaluation

The investment in roof insulation presents a financially sound opportunity as analysis indicates that the total initial investment needed for the roof insulation amounts to €42,656, with an estimated payback period of approximately two years. After this period, the savings from reduced energy costs will offset the initial investment.

Based on energy performance simulations, resulting in an overall energy demand reduction of approximately 10.7%. This reduction translates into savings on energy bills.

This evaluation highlights the economic feasibility of roof insulation as a sustainable practice contributing to both financial and environmental benefits.

Sustainable Evaluation

While roof insulation contributes to reducing overall energy demand and minimizing the use of non-renewable energy sources, the chosen material—Polystyrene Expanded Panels (EPS)—also needs to take into consideration. EPS panels provide good thermal insulation, which can significantly lower energy consumption in buildings. By improving energy efficiency, they help reduce heating and cooling costs while also decreasing greenhouse gas emissions. It is possible to say 9.0 kg CO_2/m^2 annual CO_2 reduction.

Additionally, EPS panels are durable and have a long lifespan, which reduces the need for frequent replacements and maintenance. However, it's important to note that EPS is not biodegradable, and disposal of it may be contributing to environmental pollution. (Di Gregorio, 2021)

Other Evaluations

Before installing insulation layers, it is needed to evaluate the existing roof to determine if it can support the additional weight of the materials. In some instances, roofs may require reinforcement to adequately bear this load, which could result in extra costs.

EPS is commonly used for insulation in roofs, floors, and walls, but it is not designed to be a surface that can be walked on. If maintenance requires walking on EPS, a supportive structure should be added on top to prevent damage.

6.2.3 Existing Roof's Insulation with Wood Fiber Panels

An additional design strategy for the Amaldi School complex in Orbassano emphasizes using sustainable materials to insulate existing roof structures. This method aims to improve thermal performance, cut down energy consumption, and decrease carbon emissions.

The low carbon footprint of wood, along with its insulating properties, makes wood fiber-based insulation panels an ideal choice for sustainable design. Wood fiber is entirely recyclable, biocompatible, and typically free from chemical treatments, such as formaldehyde. Wood fiber panels offer excellent thermal and sound insulation, are lightweight, and have low environmental impact while being durable and biodegradable, contributing to eco-friendly construction (Asdrubali et al., 2023).

Just as explained at the approach above, roof insulation with WFP has been chosen as an alternative due to its many benefits. It minimizes thermal bridging, a significant source of heat loss in buildings, especially through the roof.

Regulatory Framework and Financial Incentives

Just as the previous roof insulation approach, the proposal to insulate the L.S. Amaldi High School building roof will follow the DM criteria to ensure compliance with energy efficiency and sustainability standards. The project will address requirements such as controlling thermal transmittance, minimizing mold and moisture risks, and reducing overheating potential. Insulation materials will meet CE-marking standards per the Construction Products Regulation (EU) No. 305/2011 and adhere to the CAM Decree for environmental sustainability throughout their lifecycle. According to CAM's Decree, wood-based insulation materials must contain at least 70% recycled material by weight if they are predominantly from recycled sources.

As previously outlined at the Ministerial Decree, the maximum allowable thermal transmittance (Ulimit) for opaque roof structures in climate zone E, which includes Orbassano, is specified as 0.26 W/m²K. This requirement is established under Annex 1, Article 5.2, sections 1a, b, c, along with Article 4.2, section 1a, Article 1.4.3, section 2, and Appendix B.

As outlined by Prezzario (2024), costs for various insulation materials are provided per square meter or cubic meter. For a more sustainable option, Wood Fiber Panels have been selected as the material for roof insulation.

Wood Fiber Panels (Pannelli in fibra di legno) 100 Kg/m³

- 20mm thick: €8.51 per square meter.
- 40mm thick: €9.01 per square meter.
- 60mm thick: €13.53 per square meter.

- 80mm thick: €18.03 per square meter.
- 100mm thick: €22.55 per square meter.
- Thermal conductivity: Lambda ≤ 0.040 W/mK.

This material can cater to thermal insulation needs with varying thickness and density options. For the L.S. Amaldi High School building WFP roof insulation design proposal costs per square meter that are indicated above are going to be considered.

Characteristic of Roof Insulation

Improving thermal insulation in buildings is among the most effective ways to achieve energy savings by reducing heat transfer through building envelopes. Insulation materials can be classified into four groups based on their raw materials, with plant-based options, such as straw, rice husks, and wood shavings, made from agricultural and forestry byproducts. This approach will utilize a plant-based insulation option. (Liu et al., 2017)

Wood fiber panels typically have a lifespan of 20 to 30 years, with signs of degradation potentially starting as early as 15 years after installation. For more detailed information, you can check the original source. (When to Replace Your Home Insulation, n.d.) Wood fiber insulating panels are environmentally sustainable and biodegradable, providing excellent thermal performance. These panels contribute to energy efficiency in buildings while minimizing environmental impact. For more information, you can refer to relevant sources. (Asdrubali et al., 2023)

The choice of Wood Fiber as an insulation material is due to its composition of natural fibers, offering durability, moderate strength, and ease of cutting. However, it has some drawbacks: it can be unstable, susceptible to moisture-related deterioration, and lacks strong fire resistance (What Are the Types of Roofing Insulation?, n.d.)

Technical Information of Roof Insulation

According to the Ministerial Decree, major renovations on existing buildings must include several key layers arranged in a specific sequence:

1. External Waterproofing Layer (Roof Covering): This top layer shields the roof from rain, snow, and wind, using durable materials like tiles or weather-resistant membranes.

2. Thermal Insulation Layer: Insulation materials, such as polystyrene, wood fiber, or polyurethane, are applied here, with thickness determined by energy efficiency standards.

3. Vapor Barrier: Positioned below the insulation, this layer prevents moisture from indoor air from reaching the insulation and causing condensation.

4. Air Gap (Optional, for Ventilated Roofs): An air gap between the insulation and structural support allows airflow, reducing moisture and enhancing thermal performance.

5. Structural Support Layer: The base structure, typically made of wood, concrete, or steel, supports the insulation and other layers.

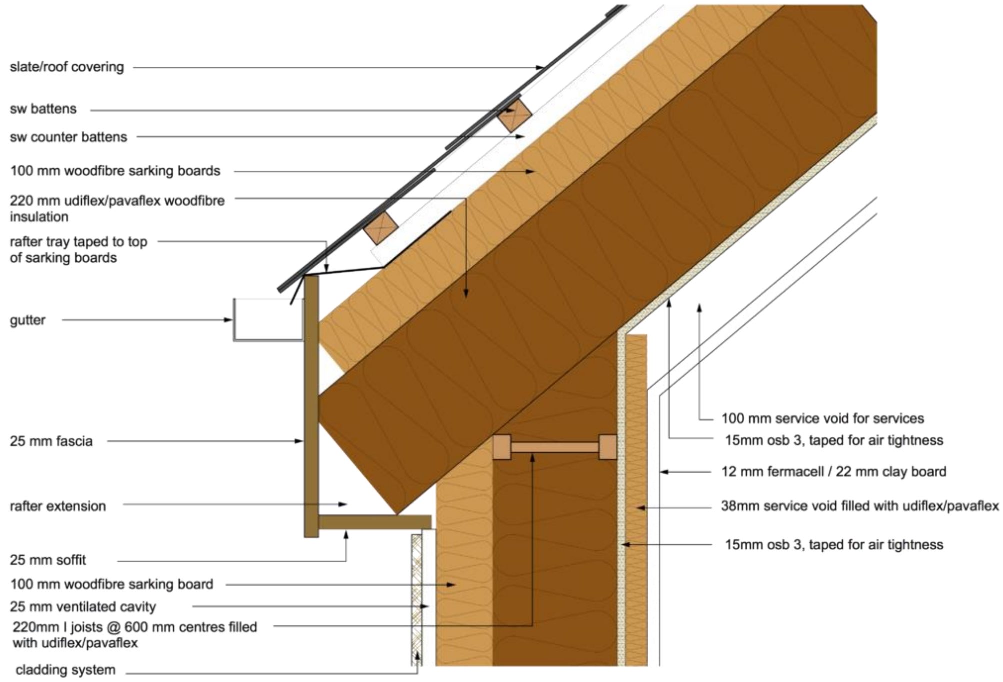


Figure 86 Composition of an insulated roof with food fiber (Brookman, n.d.)

As outlined in the Ministerial Decree, the proposed design for an insulated roof includes the following layers:

Existing Roof Layers (Structural Support): The current reinforced concrete roof will be retained, as any structural modifications would incur substantial costs.

Vapor Barrier: A 15mm vapor barrier will be installed beneath the insulation to prevent moisture from the interior from penetrating the insulation layer. This will help avoid condensation problems that could lead to mold growth or material degradation.

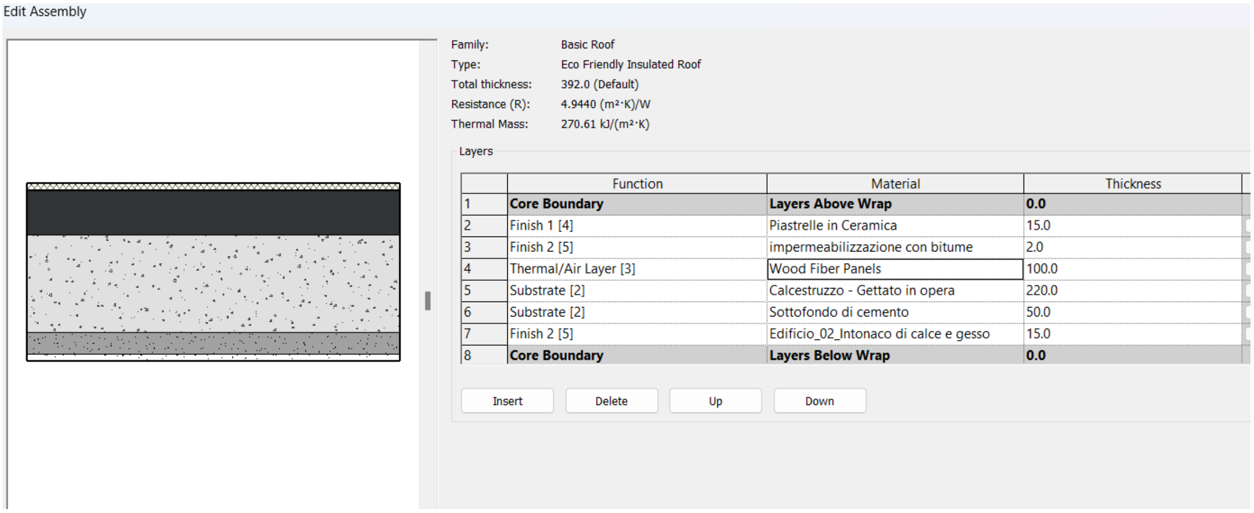
Thermal Insulation Layer (WFP): A layer of Wood Fiber Panels will be added beneath the waterproofing layer for insulation. This layer will be 100mm thick, in compliance with Italian energy efficiency standards, ensuring optimal thermal performance.

External Waterproofing Layer (Roof Covering): The top layer will either maintain the same material as the existing structure or be updated to use weather-resistant materials, such as tiles or a waterproof membrane. This layer is essential for protecting the insulation and underlying layers from exposure to weather elements.

Application of Edilclima Software

Similar to previous methods, this design process will utilize the BIM software Revit alongside Edilclima to ensure compliance with Italian regulations for upgrading school facilities. This approach enables precise simulations of building performance and energy efficiency while meeting legal standards. The process begins with modeling an insulated roof in Revit, ensuring all design layers and specifications align with the requirements established in prior stages.

Starting with creating WFP Insulated Roof at Revit and applying to related roofs.



Edit Assembly

Family: Basic Roof
Type: Eco Friendly Insulated Roof
Total thickness: 392.0 (Default)
Resistance (R): 4.9440 (m²·K)/W
Thermal Mass: 270.61 kJ/(m²·K)

Layers

	Function	Material	Thickness
1	**Core Boundary**	**Layers Above Wrap**	**0.0**
2	Finish 1 [4]	Piastrelle in Ceramica	15.0
3	Finish 2 [5]	impermeabilizzazione con bitume	2.0
4	Thermal/Air Layer [3]	Wood Fiber Panels	100.0
5	Substrate [2]	Calcestruzzo - Gettato in opera	220.0
6	Substrate [2]	Sottofondo di cemento	50.0
7	Finish 2 [5]	Edificio_02_Intonaco di calce e gesso	15.0
8	**Core Boundary**	**Layers Below Wrap**	**0.0**

Insert Delete Up Down

Figure 87 Screenshot of WFP Insulated Roof on Revit Software

1. **Ceramic Tiles (15mm):** This layer serves as the final roof coating, offering both weather protection.
2. **Bituminous Waterproofing Layer (2mm):** Ensures waterproofing to shield the roof from moisture penetration.
3. **Wood Fiber Panels (100 mm)** Insulates the roof to minimize heat transfer and enhance energy efficiency, with a thickness optimized for effective thermal performance using sustainable materials.
4. **Existing Structure (220.0 mm):** A 220 mm existing structural layer adds durability and support to the roof.
5. **Finishing:** The final 15 mm layer of lime and plaster provides a smooth, protective coating to the roof surface.

The Total thickness of this assembly is 392 mm (or 39.2 cm), which includes all layers with a thermal resistance of 4.94 $m^2 \cdot K/W$ and U value of 0.24 W/m^2K.

After completing the insulated roof design for the L.S. Amaldi High School building in Revit, a WFP insulation scenario was introduced to Edilclima EC700 software. To evaluate the improvements, all relevant data—such as climate conditions, system specifications, heating and cooling systems, mechanical ventilation, lighting, hot water production, and energy sources—was entered to match the existing building setup closely.

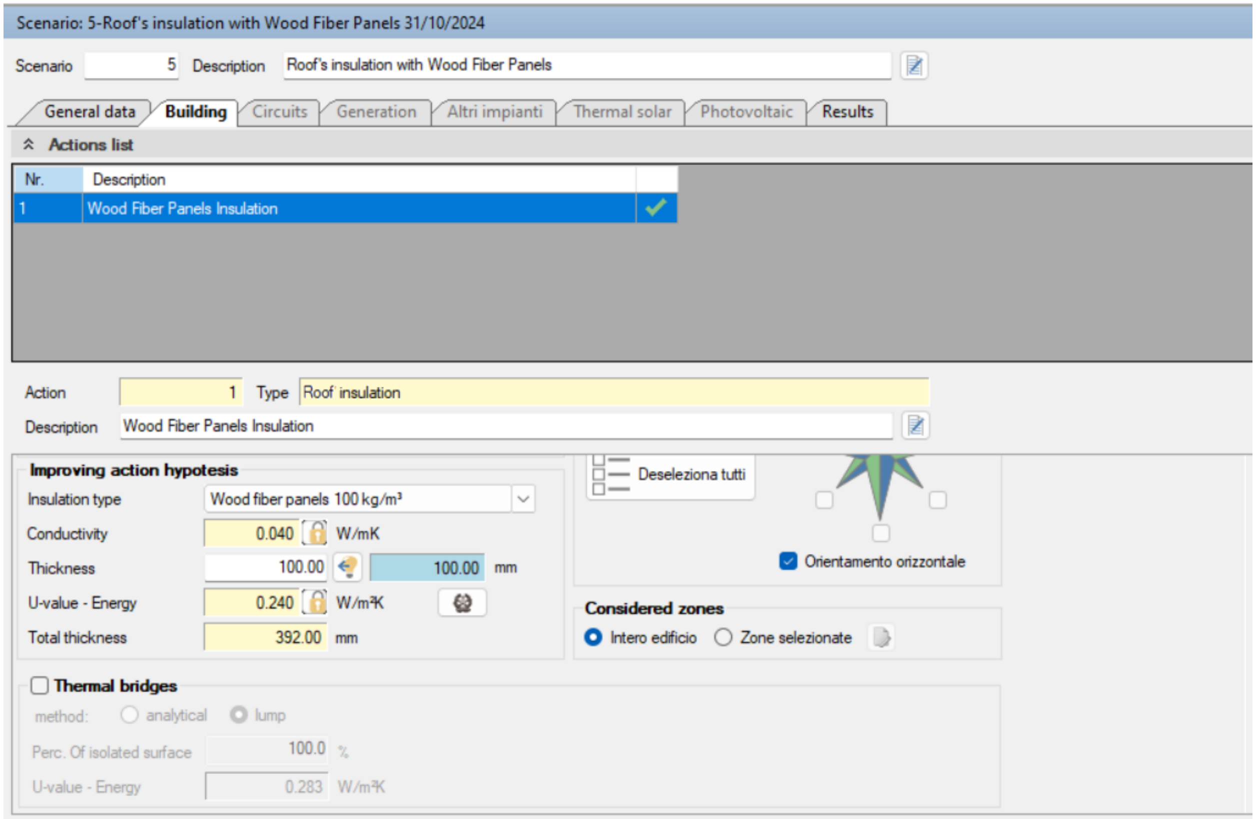


Figure 88 Edilclima EC700 Scenario for Roof Insulation with WFP

A scenario was created that shows roof insulation with WFP. The values for thermal conductivity, U-value, and thickness of the roof were manually input according to the guidelines set by the Ministerial Decree and the UNI 11235:2015 standard. Thermal transmittance (Ulimit) for opaque roof structures has been set at 0.24 W/m²K.

Results

Service	Stato di fatto [Sm130]	Scenario [Sm130]	Δ [%]
Heating (H)	226706	203875	-10.1
Domestic hot water (W)	0	0	0.0
Cooling (C)	0	0	0.0
Ventilation (V)	0	0	0.0
Lighting (L)	0	0	0.0
Transport (T)	0	0	0.0
Overall (Gl)	226706	203875	-10.1

Figure 89 Comparative Result of Energy demand for Roof Insulation with WFP Scenario

A comparative scenario was created by simulating the building's energy performance both before and after adding insulation layers to the roof. The findings reveal a decrease in heating demand, enabling a precise calculation of the energy savings linked to the roof installation. Specifically, the non-renewable energy performance (EPgl, nren) for the existing building was recorded at 226,706 kWh/m² annually, but after implementing the WFP insulation, this value dropped to 203,875 kWh/m² per year. This change leads to an overall reduction in energy demand of about 10.1%.

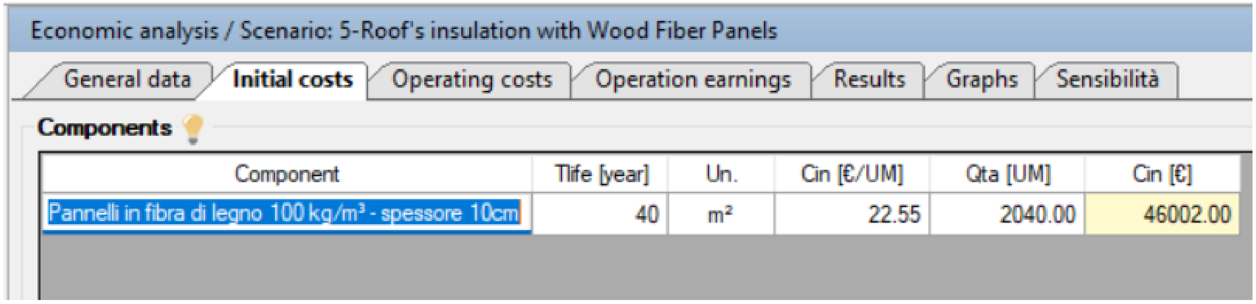


Figure 90 Initial Costs of insulation with WFP

The initial cost of €22.55 per square meter was recorded, as referenced by Prezzario (2024). The analysis is based on a financing period of 20 years with a 1% interest rate. Maintenance and insurance costs are assumed to be 5% of the total system cost, while management costs are calculated at 0.5%. Given that prices may vary depending on the region and location of the building, a 5% inflation rate for non-renewable energy sources is applied, as suggested by Testi et al. (2017).

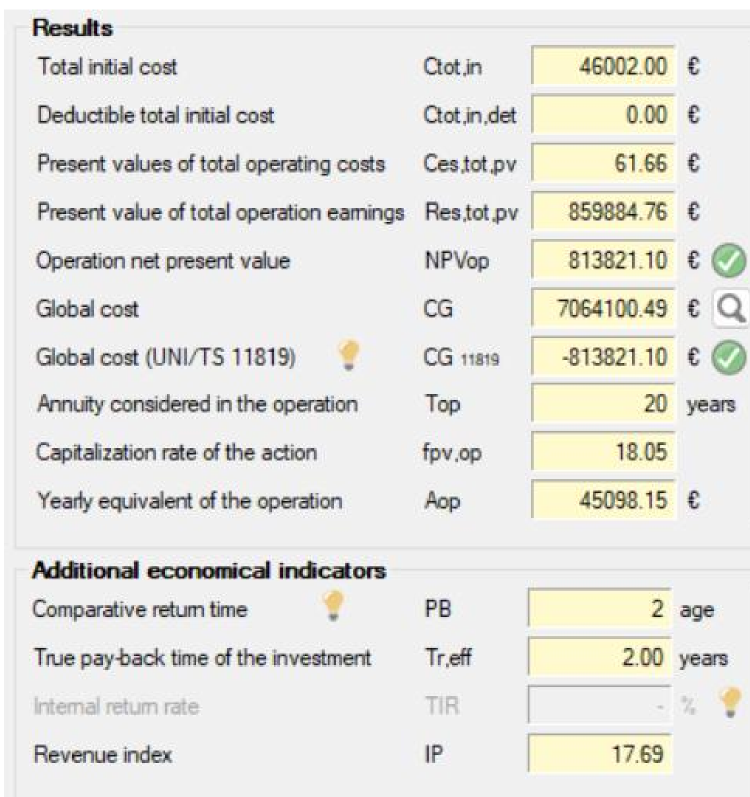


Figure 91 Economic Evaluation of Roof Insulation with WFP

The economic analysis indicates that the total initial investment needed for the roof insulation with WFP amounts to €46,002, with an estimated payback period of 2 years. After this period, the savings from reduced energy costs will offset the initial investment.

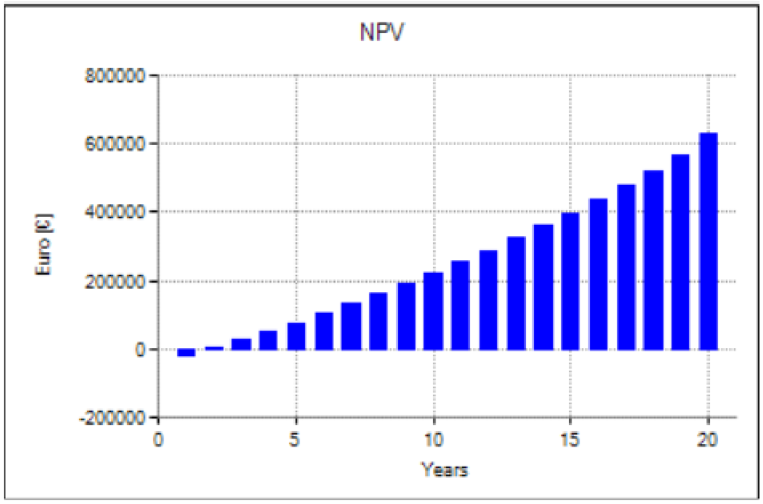


Figure 92 Graph from EC 700 regarding the investment of insulation with WFP.

Similarly to the insulation with EPS results, the graph depicts the net present value (NPV) of an investment over time, indicating that cash flow becomes positive around the second year. The blue bar represents the NPV, which transitions to a positive value after a specific period and continues to rise. This upward trend indicates that the present value of future cash inflows exceeds the initial investment costs. A positive NPV signifies that the investment is financially viable and is expected to be profitable over the long term.

Another key metric to consider is CO_2 reduction, which can be assessed by calculating emissions savings based on the overall reduction in energy consumption. By determining total energy savings, it becomes possible to quantify the CO_2 emissions avoided. For instance, using Italy's average emissions factor of 319 g CO_2eq per kWh (Current emissions in Italy, n.d.) a 10.7% decrease in energy demand, translating to a total saving of 27,504 kWh, results in a significant reduction in emissions. Applying the factor of 0.31 kg CO_2 per kWh, the total CO_2 reduction is calculated as:

27,504 kWh x 0.31 kg = 8,526.9kg CO_2 is total CO_2 reduction annually.

To express this on a per-square-meter basis, divide the total reduction by the building's area, resulting in approximately 8.6 kg CO_2/m^2 annually.

Evaluation

Economic Evaluation

The investment in roof insulation with WFP presents a financially sound opportunity as analysis indicates that the total initial investment needed for the roof insulation amounts to €46,002, with an estimated payback period of approximately two years. After this period, the savings from reduced energy costs will offset the initial investment.

Based on energy performance simulations, resulting in an overall energy demand reduction of approximately 10.1%. This reduction translates into savings on energy bills.

This evaluation highlights the economic feasibility of roof insulation as a sustainable practice contributing to both financial and environmental benefits.

Sustainable Evaluation

Wood fiber panels offer excellent thermal insulation, helping to lower building's energy consumption. Energy efficiency, they help cut heating costs and reduce greenhouse gas emissions. Alongside biodegradability, lightweight structure, low environmental impact, and durability, these features make wood fiber panels an attractive choice for sustainable building materials.

In terms of environmental impact, calculations indicate that wood fiber insulation can achieve an annual CO_2 reduction of approximately 8.6 kg CO_2/m^2, underscoring its support carbon footprint reduction efforts in L.S. Amaldi High School building approach.

Other Evaluations

Before installing insulation layers, it is essential to assess the current roof structure to ensure it can handle the added weight of new materials. In some cases, reinforcement may be necessary to support this load, potentially leading to additional costs.

Additionally, due to recent fire safety regulations, the combustibility of wood fiber panels must be carefully considered (Asdrubali et al., 2023).

6.3 Evaluations Of the Approaches

6.3.1 Evaluations Regarding Energy Efficiency Hypothesis

In the previous chapters two different hypotheses are conducted to reduce the energy consumption for the L.S. Amaldi High School building. First hypothesis was about integrating solar panels with for the existing building and second hypothesis about replacing the existing condensing boilers with high efficiency models.

The economic evaluation for installing solar panels at the L.S. Amaldi High School building shows strong financial viability, with an initial investment of €110,250 and a payback period of approximately 6 years (as per UNI EN 15459). After this period, energy savings will cover the initial costs, and net present value (NPV) continues to grow, confirming profitability over the long term. Solar panel integration supports renewable energy generation and reduces 64 kg of CO_2 emissions annually, aligning with long-term sustainability goals thanks to consistent renewable energy production. Before installing solar panels, the roof's structural integrity must be assessed to ensure it can bear the weight of solar panels; some reinforcement may be required. Aesthetics should also be considered, as solar panels could impact the building's visual appearance, which may concern some stakeholders. Under Legislative Decree n. 28/2011, at least 55% of a building’s energy demand for heating, cooling, and domestic hot water (DHW) must be met by renewable sources. In this scenario, photovoltaic (PV) panels serve as a renewable energy source. Additionally, financial incentives like *Conto Termico 2.0* are available in Italy to support the integration of renewable energy in school building retrofits, making projects like these more economically viable.

Second approach, replacing the existing condensing boilers with high efficiency models shows the total initial investment for replacing condensing boilers is €105,996, with a payback period of about 3 years goes along with UNI EN 15459, meaning the project will recoup costs quickly through energy savings. A positive net present value (NPV) of €943,368 in 20 years highlights its financial appeal. Condensing boilers are highly efficient, consuming less fuel for the same heat output and reducing carbon emissions compared to non-condensing models. This upgrade yields a 13.3% reduction in non-renewable energy use and an annual CO_2 emissions reduction of 11.19 kg annually, contributing to a lower carbon footprint for the heating system.

A table has been developed to highlight various factors to consider when integrating design approaches based on building rating systems, in alignment with European Technical Standards.

Approach	Regulatory and Standard Compliance	Incentives	Payback Period	Initial Cost	Maintenance Cost	Energy Savings Annually (kWh/m²)
Solar Panel Integration	Yes	Yes	6 Years	€110,250	€5.512	27.95 kWh/m²
Replacing Existing Condensing Boilers	Yes	No	3 Years	€105,996	€5.299	30.88 kWh/m²

Table 15 Economical Comparison for Energy Efficiency Hypothesis

The table above summarizes and compares two energy efficiency approaches regarding economic considerations. It indicates that both options are viable in terms of regulatory and standard compliance. However, only solar panel installations benefit from an incentive known as Conto Termico 2.0, which could help offset initial costs. The table also highlights the payback periods for the two approaches, revealing that replacing existing condensing boilers offers the shortest payback period of just three years, making it an appealing choice. Additionally, with lower initial and maintenance costs alongside significant energy savings, replacing existing condensing boilers emerges as the more attractive option.

Approach	Uses Sustainable Energy Source	Regulatory and Standard Compliance	Life Span	Recyclability	CO_2 Reduced Annually (kg)
Solar Panel Integration	*Yes*	*Yes*	*25-30 years*	*High*	*64 kg*
Replacing Existing Condensing Boilers	*No*	*Yes*	*15-20 years*	*Moderate*	*11.1 kg*

Table 16 Sustainability Comparison for Energy Efficiency Hypothesis

The table above summarizes and compares two energy efficiency approaches in terms of sustainability considerations. The Solar Panel Integration Approach uses the sustainable energy source of the sun, while condensing boilers rely on methane gas, which is not a sustainable energy source. Although both approaches meet regulatory and standard compliance, the sustainability comparison also reveals their lifespans. Solar panels have a lifespan of 25 to 30 years and exhibit high recyclability, which enhances their end-of-life considerations compared to the other approach. Data from the Edilclima application further indicates that solar panel integration results in a greater annual CO_2 reduction of 64 kg, whereas replacing existing condensing boilers only achieves a reduction of 11 kg. Considering all these factors, it can be concluded that solar panel integration is the most sustainable approach for energy efficiency.

While solar panel integration is the more sustainable option of the two, sustainability is not the only factor influencing the decision regarding the best approach for retrofitting high school buildings in Italy. Replacing existing condensing boilers presents a more appealing economic choice due to its lower cost and shorter payback period, coupled with superior annual energy savings. As a result, this option is going to be adopted for the energy efficiency hypothesis of the L.S. Amaldi High School building.

6.3.2 Evaluations Regarding Insulation Hypothesis

In the previous chapters, three strategies for enhancing roof insulation for the L.S. Amaldi High School building were explored. The first approach focused on optimizing a green roof, the second involved insulating the roof with EPS (expanded polystyrene), and the third considered using wood fiber panels for insulation.

The three insulation approaches comply with regulations setting a maximum thermal transmittance limit of 0.26 W/m^2K for roofs in climate zone E (Orbassano), as outlined in Annex 1. The Ministerial Decree of June 26, 2015, provides guidelines for designing and insulation of roofs in Italy, promoting sustainable urban development. Additionally, all building materials meet the CAM Decree's sustainability standards across their lifecycle.

The first approach proposed extensive green roof for the L.S. Amaldi High School building with the initial investment required for the green roof design is €111,526 and 5-year payback period and long-term financial benefits through energy savings. Extensive green roofs are low maintenance with only €2.0 per square meter. They support urban biodiversity, aid in stormwater management, and improve air quality, reducing CO_2 emissions by 171 kg annually. When it comes to points to be aware of, plant selection should align with the local climate, and the roof structure must be assessed for weight capacity, as reinforcement may be necessary, potentially adding costs.

Second approach, the roof insulation with EPS investment for the L.S. Amaldi High School building, costing €42,656, has a payback period of two years due to energy savings, resulting in a 10.7% reduction in energy demand. EPS panels, chosen for their thermal efficiency, contribute to CO_2 reduction (9.0 kg/m^2 annually) but require careful disposal as they are not biodegradable and may cause environmental harm. Additionally, existing roof capacity must be assessed for added weight, and if EPS must be walked on, a protective structure should be installed.

The last approach is roof insulation with wood fiber panels (WFP), has a €46,002 investment and a payback period of about two years, achieves a 10.1% reduction in energy demand, making it financially and environmentally viable. WFP provides strong thermal insulation, reducing energy usage, heating costs, and greenhouse gas emissions. It also has sustainable qualities, including biodegradability, lightness, durability, and low environmental impact, achieving an estimated annual CO_2 reduction of

8.6 kg/m². These features highlight WFP's suitability for the L.S. Amaldi High School building's sustainability goals.

A table has been created to emphasize various factors to consider when incorporating design strategies aligned with building rating systems, in accordance with European Technical Standards related to insulation.

Approach	Regulatory and Standard Compliance	Incentives	Payback Period	Initial Cost	Maintenance Cost Annually	Energy Savings Annually (kWh/m²)
Green Roof Optimization	Yes	No	5 Years	€111,526	€4.080	23.12 kWh/m²
Roof Insulation with EPS	Yes	No	2 Years	€42,656	€2.132	23.73 kWh/m²
Roof Insulation with WFP	Yes	No	2 Years	€46,002	€2.300	23.31 kWh/m²

Table 17 Economical Comparison for Insulation Hypothesis

The table above provides an economic comparison of three insulation strategies. While all three comply with regulatory standards, no incentives are available to offset initial costs for 2024 in Italy. EPS roof insulation and wood fiber panel (WFP) insulation both offer a short payback period of 2 years, making them financially attractive. In contrast, green roof optimization has a longer 5-year payback period and is significantly more expensive, with an initial cost of €111,526, over double that of the other two options—particularly EPS, which has the lowest initial cost at €42,656. Additionally, the maintenance costs for green roofs are nearly double those for the other methods, which could deter preference for this option.

In terms of energy efficiency, EPS insulation records the highest annual energy savings at 23.73 kWh/m², with WFP coming in second. Considering its low initial and maintenance costs, short payback period, and notable energy savings, EPS roof insulation emerges as the most economical and preferable solution among the three approaches.

Approach	Uses Biodegradable Materials	Meets CAM Decree's Sustainability Standards	Life Span	Recyclability	CO_2 Reduced Annually (kg)
Green Roof Optimization	*Yes*	Yes	*50 years*	*High*	*171 kg*
Roof Insulation with EPS	*No*	Yes	*50 years*	*Moderate*	*9 kg*
Roof Insulation with WFP	*Yes*	Yes	*15 years*	*High*	*8.6 kg*

Table 18 Sustainability Comparison for Insulation Hypothesis

The table above presents a sustainability comparison of three insulation strategies. Both green roof optimization and roof insulation using Wood Fiber Panels incorporate biodegradable materials, whereas roof insulation with EPS does not. All three methods comply with the sustainability standards set by the CAM decree. This includes ensuring that green roofs meet thermal and material requirements, that insulation with EPS consists of at least 15% cumulative recycled content, and that insulation made from Wood Fiber Panels contains a minimum of 70% recycled wood-based materials.

Another aspect of the comparison examines the lifespan of the various approaches. Both green roofs and insulation with EPS have a lifespan of 50 years, while roof insulation with Wood Fiber Panels has a significantly shorter lifespan of only 15 years, making it a less appealing option. In terms of recyclability, roof insulation with EPS is rated as moderate, while the other two approaches are considered high. Lastly, the annual CO_2 reduction is highest for the green roof integration, with a reduction of 171 kg, making it the most favorable option, compared to only 9 kg for insulation with EPS and 8.6 kg for Wood Fiber Panels. Considering the sustainability aspects, the green roof optimization approach appears to be the most sustainable of the three options.

While green roof optimization is the more sustainable option of the three approaches, sustainability is not the only factor influencing the decision regarding the best insulation approach for retrofitting high school buildings in Italy. Existing roof insulation with EPS presents a more appealing economic choice due to its lower cost and shorter payback period and with superior annual energy savings. As a result, this option is going to be adopted for the insulation hypothesis of the L.S. Amaldi High School building.

7. RECOMMENDATION

In the previous sections, the design hypothesis for the L.S. Amaldi High School building was investigated in two parts. The first part concentrated on improving energy efficiency in the L.S. Amaldi High School building by comparing two different approaches, determining that replacing the existing condensing boilers is the most cost-effective solution. The second part analyzed three insulation methods to identify the best option, concluding that the roof insulation with EPS is the most beneficial choice. For the recommendations, both options will be integrated in order to have the best results for the case study.

A summary of the approaches and key points considered, like those in the previous analyses, is provided below.

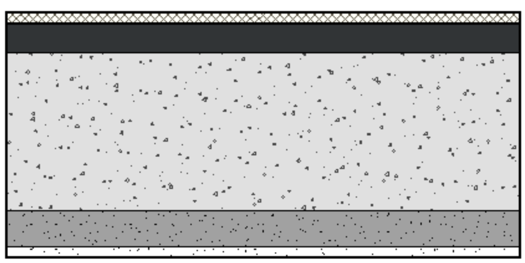
To ensure compliance and improve efficiency in the L.S. Amaldi High School building high school building, the existing condensing boilers, installed in 2005 with an efficiency of 79%, will be replaced. Legislative Decree 192/2005 requires a minimum 90% efficiency for heat generators, which the current system does not meet, while the EU's Energy Performance of Buildings Directive (EPBD) and Italian standard UNI/TS 11300-2 emphasize the importance of energy-efficient upgrades. The chosen replacement is a four-star-rated, 500 kW floor-standing condensing boiler, aligning with these standards and priced at €35,332.15 per unit, per the Prezzario 2024 guide.

For the L.S. Amaldi High School building roof insulation proposal, EPS insulation is selected due to its durability, affordability, and effectiveness in reducing heating demand. The June 26, 2015, decree underscores the need for efficient design and construction practices, setting minimum energy performance standards for building elements like roofing. For climate zone E, which includes Orbassano, the maximum allowable thermal transmittance (Ulimit) for opaque roof structures is 0.26 W/m²K, as per Annex 1 and related articles. Building materials must also comply with the CAM (Minimum Environmental Criteria) decree's sustainability standards over their lifecycle. According to CAM, EPS insulation must have at least 15% recycled, recovered, or by-product content by weight, with a minimum of 10% from recycled sources. In line with Prezzario (2024), the cost for 40 mm thick Expanded Polystyrene (EPS) panels (density: 35 Kg/m³) is €20.91 per square meter.

Application of Edilclima Software

In this segment, energy efficiency and insulation approaches will be combined to identify the best possible improvements for the L.S. Amaldi High School building case study. As in the previous segments, the Edilclima application will be used alongside the Revit BIM program to achieve results.

First, the insulated roof was modeled in Revit, ensuring that all design layers and specifications adhered to the standards outlined in previous steps.



Family: Basic Roof
Type: Insulated Roof
Total thickness: 342.0 (Default)
Resistance (R): 3.3815 (m²·K)/W
Thermal Mass: 323.53 kJ/(m²·K)

Layers

	Function	Material	Thickness
1	**Core Boundary**	**Layers Above Wrap**	**0.0**
2	Finish 1 [4]	Piastrelle in Ceramica	15.0
3	Finish 2 [5]	impermeabilizzazione	2.0
4	Thermal/Air Layer [3]	Polystyrene	40.0
5	Substrate [2]	Calcestruzzo - Gettato	220.0
6	Substrate [2]	Sottofondo di cement	50.0
7	Finish 2 [5]	Edificio_02_Intonaco d	15.0
8	**Core Boundary**	**Layers Below Wrap**	**0.0**

Insert Delete Up Down

Figure 93 Screenshot of Insulated Roof with EPS on Revit Software

1. **Ceramic Tiles (15 mm):** The outermost layer provides weather protection and aesthetic value.

2. **Bituminous Waterproofing Layer (2 mm):** This layer prevents moisture infiltration, safeguarding the roof.

3. **Polystyrene Insulation (40 mm):** Acts as an insulating layer to reduce heat transfer, enhancing energy efficiency. This thickness ensures effective thermal performance.

4. **Existing Structure (220 mm):** The 220 mm structural layer provides the roof's core strength and support.

5. **Finishing Layer (15 mm):** A final lime and plaster layer adds a smooth, protective finish.

The total assembly thickness is 342 mm (or 34.2 cm), with a thermal resistance of 3.38 m²·K/W and a U-value of 0.24 W/m²K. Once the insulated roof design was completed in Revit, the model was transferred to Edilclima software via the EC770 Plug-in, allowing for analysis of the roof modifications' impact on energy efficiency.

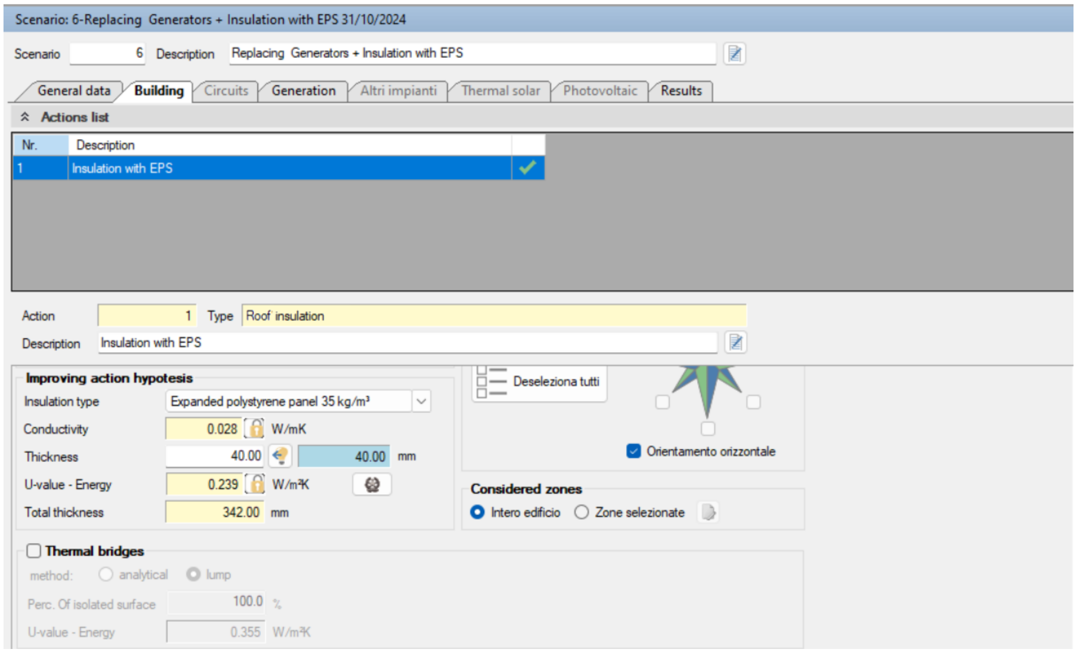


Figure 94 Edilclima EC700 Scenario for Roof Insulation with EPS

A scenario was created to illustrate roof insulation, with thermal conductivity, U-value, and EPS insulation thickness manually input according to the Ministerial Decree and UNI 11235:2015 standards. The thermal transmittance (Ulimit) for opaque roof structures was set at 0.239 W/m²K.Edilclima supports compliance with UNI/TS 11300-2 technical standards for heating systems, offering precise assessments of building performance in line with local regulations.

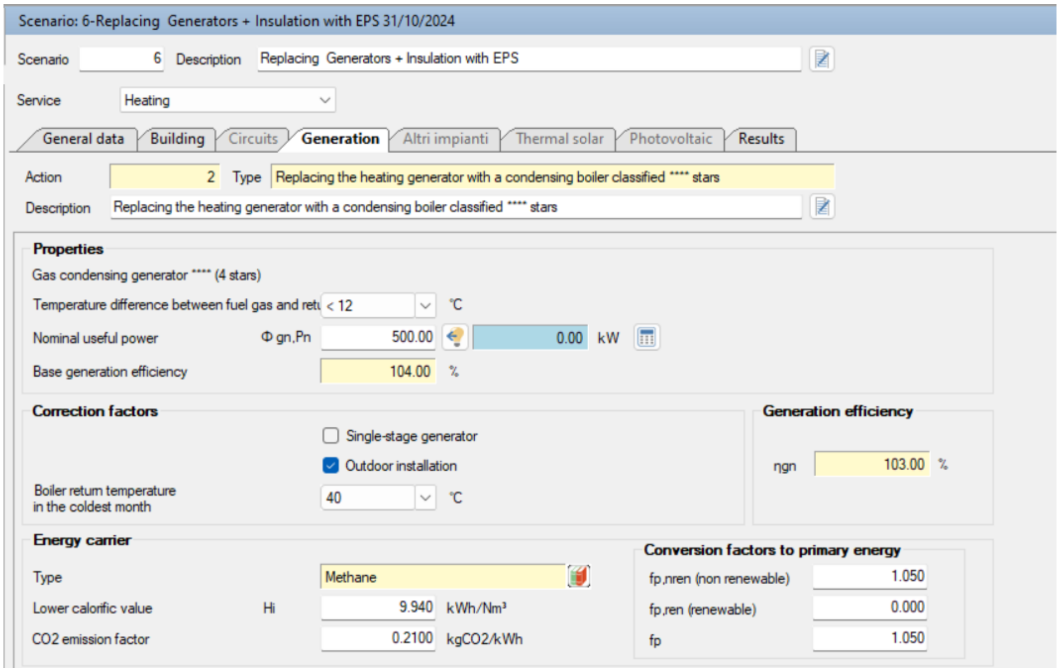
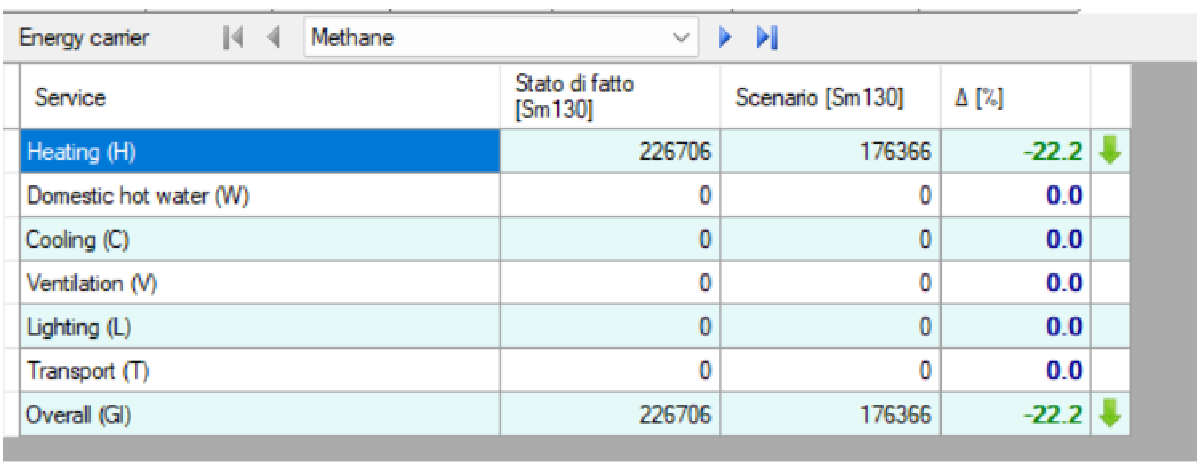


Figure 95 Edilclima EC700 Scenario for Replacing Existing Condensing Boilers

After evaluating the existing condensing boilers, a decision was made to replace them with high-efficiency, four-star-rated condensing boilers. To ensure an accurate analysis, detailed information on nominal useful power, installation location, and energy type characteristics was entered, enabling precise calculations and optimization of boiler performance.

Results



Service	Stato di fatto [Sm130]	Scenario [Sm130]	Δ [%]
Heating (H)	226706	176366	-22.2
Domestic hot water (W)	0	0	0.0
Cooling (C)	0	0	0.0
Ventilation (V)	0	0	0.0
Lighting (L)	0	0	0.0
Transport (T)	0	0	0.0
Overall (Gl)	226706	176366	-22.2

Figure 96 Comparative Result of Energy demand for combined approach.

A comparative scenario was developed by simulating the building's energy performance both before and after the installation of insulation layers on the roof and the replacement of the existing condensing boilers with high-efficiency models. The results indicate a reduction in heating demand, allowing for an accurate calculation of energy savings associated with the roof insulation. Specifically, the non-renewable energy performance (EPgl, nren) for the existing building was measured at 226,706 kWh/m² annually, but after the installation of EPS insulation and the replacement of the condensing boilers, this figure decreased to 176,366 kWh/m² per year. This change represents an overall reduction in energy demand of approximately 22.2%.

Economic analysis / Scenario: 6-Recommendation Generators + Insulation with EPS

General data | **Initial costs** | Operating costs | Operation earnings | Results | Graphs | Sensibilità

Components

Component	Tlife [year]	Un.	Cin [€/UM]	Qta [UM]	Cin [€]
Pannelli in fibra di legno 100 kg/m³ - spessore 10cm	40	m²	20.91	2040.00	42656.40
Caldaia - a condensazione	20	pz	35332.00	3.00	105996.00

Figure 97 Initial Costs for combined approach

The initial cost of EPS material is recorded at €20.91 per square meter, while the unit price for each 500-kW condensing boiler is €35,332, applicable to all three existing boilers as noted in Prezzario (2024). Just like the previous approaches, the combined analysis assumes a financing period of 20 years with a 1% interest rate. Maintenance and insurance costs are estimated at 5% of the total system cost, while management expenses are calculated at 0.5%. Considering potential regional price variations, a 5% inflation rate for non-renewable energy sources is applied, following the recommendations of Testi et al. (2017).

Results

Total initial cost	Ctot,in	148652.40	€
Deductible total initial cost	Ctot,in,det	0.00	€
Present values of total operating costs	Ces,tot,pv	49018.65	€
Present value of total operation earnings	Res,tot,pv	1780324.27	€
Operation net present value	NPVop	1582653.21	€
Global cost	CG	6295268.38	€
Global cost (UNI/TS 11819)	CG 11819	-1582653.21	€
Annuity considered in the operation	Top	20	years
Capitalization rate of the action	fpv,op	18.05	
Yearly equivalent of the operation	Aop	87703.23	€

Additional economical indicators

Comparative return time	PB	3	age
True pay-back time of the investment	Tr,eff	3.00	years
Internal return rate	TIR	-	%
Revenue index	IP	10.65	

Figure 98 Economic Evaluation for combined approach

The economic evaluation of the combined approach indicates that the total initial cost is €148,652, with an estimated payback period of 3 years. After this period, the savings from decreased energy costs will compensate for the initial investment.

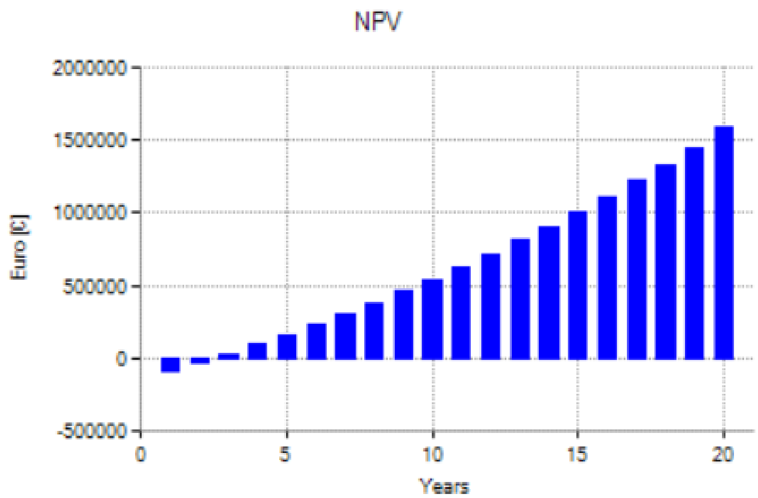


Figure 99 Graph from EC 700 regarding combined approach.

The graph illustrates the net present value (NPV) of an investment over time, showing that cash flow turns positive around the third year. The blue bar represents the NPV, which shifts to a positive value after a certain period and continues to increase. This upward trend indicates that the present value of future cash inflows surpasses the initial investment costs. A positive NPV signifies that the investment is financially viable and is anticipated to yield profits in the long run.

Another important metric to consider is CO_2 reduction, which can be evaluated by calculating emissions savings based on the overall decrease in energy consumption. By determining the total energy savings, it becomes feasible to quantify the CO_2 emissions that have been avoided. For example, using Italy's average emissions factor of 319 g CO_2eq per kWh (Current emissions in Italy, n.d.) a 22.2% reduction in energy demand, equating to a total saving of 57,064 kWh, leads to a significant decrease in emissions. By applying the factor of 0.31 kg CO_2 per kWh, the total CO_2 reduction can be calculated as follows:

57,064 kWh x 0.31 kg = 17,689.84 kg CO_2 is total CO_2 reduction annually.

To express this on a per-square-meter basis, divide the total reduction by the building's area, resulting in approximately 17.78 kg CO_2/m^2 annually.

Evaluation

Economic Evaluation

The economic evaluation of the combined approach demonstrates a viable investment for improving the energy efficiency of the building. With a total initial cost of €148,652, the estimated payback period is just 3 years, indicating a relatively quick return on investment. The positive net present value (NPV) of €1.5+ million further underscores the attractiveness of this investment.

Sustainable Evaluation

While roof insulation plays a significant role in decreasing overall energy demand and minimizing reliance on non-renewable energy sources, the selected material—Polystyrene Expanded Panels (EPS)—must also be evaluated. EPS panels are known for their durability and long lifespan, which reduces the frequency of replacements and maintenance. However, it is essential to recognize that EPS is not biodegradable, and its disposal may contribute to environmental pollution.

Additionally, condensing boilers are more efficient, using less fuel to produce the same amount of heat, which results in considerably lower carbon emissions compared to non-condensing models. This efficiency contributes to a reduced carbon footprint for heating systems. As a result of combined approach shows approximately 17.78 kg CO_2 reduced emissions per square meter annually.

8. CONCLUSION

In conclusion, this thesis addresses critical challenges facing numerous educational institutions in Italy, particularly those with outdated infrastructure and significant energy inefficiencies. By concentrating on the retrofitting of the Amaldi School complex in Orbassano, this study emphasizes the pressing need for modernization in school buildings, environments that are fundamental to fostering learning and development.

The research contributes to the broader discourse on sustainable architecture by examining innovative strategies that enhance energy efficiency while ensuring economic feasibility. Through the integration of advanced technologies such as Building Information Modeling (BIM) and energy analysis software Edilclima, this thesis demonstrates the potential of data-driven approaches to achieve effective retrofitting solutions aligned with European Technical Standards. Furthermore, the insights and findings from this research extend beyond the Amaldi School complex, providing a valuable reference for similar projects aimed at improving educational facilities throughout Italy.

This study utilized Building Information Modeling (BIM) to develop a detailed model of the Amaldi-Sraffa complex in Revit, enabling in-depth energy analysis based on the structure's embedded material and thermal characteristics. This approach allowed for an accurate assessment of the building's energy performance and provided a reliable baseline for evaluating various energy efficiency strategies, particularly those targeting insulation improvements. By simulating multiple retrofit scenarios, more sustainable solutions were identified and applied to optimize the complex's energy use and enhance existing conditions.

After establishing the as-built BIM model, Edilclima software was employed to perform energy efficiency calculations, ensuring compliance with Italian regulations and standards. The analysis focused specifically on Building 3 (L.S. Amaldi), as it was the only building in the complex that had not undergone improvement projects in recent years and required retrofitting.

The analysis results indicate that for energy efficiency, while solar panel integration is the more sustainable option, it is not the only factor considered in determining the optimal approach for retrofitting high school buildings in Italy. Replacing the existing condensing boilers emerges as the more economically advantageous choice, offering a lower initial cost, shorter payback period, and greater annual energy savings. Consequently, this option was selected for the energy efficiency hypothesis of the L.S. Amaldi High School building.

Similarly, for insulation strategies, although green roof optimization offers the highest sustainability, economic considerations led to the selection of the existing roof insulation with Expanded Polystyrene (EPS). This approach provides a more cost-effective solution with a shorter payback period and better annual energy savings. Therefore, EPS roof insulation was chosen for the insulation hypothesis for the L.S. Amaldi High School building.

The analysis results underscore that although sustainability was a key consideration in evaluating retrofitting strategies, it is not the only factor driving decisions for school buildings in Italy. Economic feasibility plays a larger role in determining the most viable solutions. Considering CAM (Minimum Environmental Criteria) allows for enhanced results by setting minimum environmental requirements. CAM establishes baseline standards for sustainable materials and practices, ensuring that even economically driven choices align with environmental goals. By adhering to CAM standards, the project can achieve a balanced approach, integrating sustainability and economic feasibility to meet both environmental objectives and financial constraints.

Finally, this thesis demonstrates how balancing sustainability with economic feasibility is essential in retrofitting strategies for educational buildings in Italy. By applying BIM and Edilclima, the study provides an extensive framework for evaluating energy efficiency measures that meet both environmental and financial objectives. Incorporating CAM (Minimum Environmental Criteria) ensures that each solution aligns with essential sustainability standards, even when economic factors take precedence. The findings of this research offer valuable insights not only for the Amaldi-Sraffa complex but also as a model for future projects, highlighting a practical and responsible approach to modernizing school infrastructure across Italy.

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