Comparative Analysis of Retrofitting Strategies: Northeast America's and Northern Italy's Regional Standards and Energy Goals

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Abstract

This study addresses the modern issue of climate change by focusing on the building sector's significant energy consumption, which accounts for roughly one-third of global energy use. With existing buildings identified as major contributors to Greenhouse Gas (GHG) emissions and energy waste, this research aims to explore energy retrofitting as a strategy for sustainability. By comparing retrofitting strategies within Northeast America and Northern Italy, specifically Worcester, U.S., and Lecco, Italy, this paper investigates regional standards and energy goals through a detailed analysis of two academic buildings: Stratton Hall (WPI) and Building 12 (Polimi-Lecco). The goals include designing, simulating, and comparing retrofitting solutions to meet and exceed code requirements and achieve Net Zero energy consumption. This study highlights Italy's successful retrofitting experiences to provide insight for the U.S. and potentially other countries towards more effective and worldwide applicable retrofitting strategies. The project outlines a methodology for developing accurate models of the buildings' current energy efficiency and architectural properties, designing retrofitting solutions, and synthesizing findings to propose recommendations for improving energy codes and retrofitting practices. Through this approach, the research seeks to contribute to the development of sustainable practices in the building sector, offering a path towards reduced energy consumption and a more sustainable future.

Capstone Design Statement

Environmental

The study underscores the crucial role of the building sector in global energy consumption and greenhouse gas emissions. It showcases how implementing energy retrofitting strategies offers a viable pathway to significantly reduce energy waste and emissions in existing buildings, thereby aiding global climate change mitigation efforts.

Health and Safety

Retrofitting buildings not only improves energy efficiency but also enhances indoor environmental quality. By adopting modern retrofitting practices, buildings can achieve better ventilation, air quality, and thermal comfort, positively impacting occupants' health and safety.

Constructability

The research assesses the practical aspects of retrofitting, including the feasibility of incorporating new technologies and materials into existing structures. It outlines methodologies for developing accurate building models to design effective retrofitting solutions.

Sustainability

The comparative analysis highlights Italy and Europe's success in sustainability efforts, specifically on retrofitting efforts, providing valuable lessons for the U.S. The study advocates for retrofitting as a sustainable practice, emphasizing its potential to reduce energy consumption, and contribute to environmental sustainability.

Social

By improving the energy efficiency of buildings, retrofitting has the potential to alleviate energy poverty and enhance living conditions. This research points towards a socially responsible approach to building management, where retrofitting is viewed as a favorable cost that not only improves the well being of the occupants but promotes a culturally positive view of sustainable practices.

Economic

The study touches on the economic advantages of retrofitting, including the potential cost savings of retrofitting a building and the role that economic incentives have on promoting energy retrofitting projects.

Professional License Statement

Licensure holds significant implications within the discipline of Architectural Engineering (AREN), serving as a hallmark of professional competence. Attainment of the Architectural Engineering PE License necessitates a foundational educational background from an institution endorsed by the Accreditation Board for Engineering and Technology (ABET), complemented by years of substantive work experience. Successful completion of the Fundamentals of Engineering (FE) and Principles and Practice of Engineering (PE) examinations is obligatory.

Sustaining the PE license mandates a commitment to ongoing education, involving participation in accredited courses, webinars, and similar avenues to accrue professional development hours (PDHs). Licensure functions as a critical threshold for professional standards, imbuing credibility to practitioners and engendering confidence in their competencies.

The PE license serves as a hallmark for individual practitioners, denoting a capacity to provide services directly to the public while upholding the highest standards of engineering. Moreover, many professional positions necessitate possession of this licensure as a prerequisite for employment, underscoring its intrinsic value within the industry.

From a societal perspective, licensure operates as a safeguard against potential hazards associated with inadequately qualified individuals in the field. Without such licensure, the public could be exposed to risks inherent in structures and services provided by less qualified practitioners. The PE license, therefore, assumes a pivotal role in assuring the public of the stringent standards met by licensed engineers, thereby enhancing overall safety and reliability.

Acknowledgements

Our Major Qualifying Project (MQP) benefited significantly from the contributions and support of several key individuals and institutions. We want to acknowledge the invaluable guidance provided by our advisors at WPI, Professor Van Dessel and Professor El-Korchi for their hard work and commitment to our work. Without their continued support of the project we would have had difficulty making the most of the opportunity we were given. We also want to give thanks to our professors based at Milan Polytechnic University who were essential in allowing us to succeed in our work. Professor Salvalai and Professor Iannaccone allowed us to gain a strong understanding of international energy policy and whose expertise was crucial to our project's success.

We are thankful to Milan Polytechnic University for hosting us and facilitating our research in Italy, and Worcester Polytechnic University for supporting our international study opportunity. Special thanks go to Nick Palumbo for his assistance in obtaining essential construction documents for Stratton Hall. This project represents a collaborative effort that bridged continents and academic disciplines, and we are grateful for the support and opportunities provided to us.

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Introduction

Design Problem

As the global climate scenario grows increasingly worrisome, addressing climate change is emerging as one of the biggest challenges of the 21st century. As we examine potential sources of energy consumption, we must look towards the building sector. The ongoing need to integrate modern technologies and energy-efficient systems into buildings is crucial for sustainability and reducing the significant energy consumption—roughly one-third globally—that the building sector accounts for (Shaikh et al., 2017). Therefore, investigating means to push the building sector towards sustainability by lessening its energy usage emerges as a central design problem in the coming decades.

Existing buildings emerge as large contributors to this issue, making energy retrofits of these buildings substantial prospects for reducing GHG and energy consumption (Shaikh et al., 2017). While this is an issue worldwide, we can see in the United States, a current world leader, that the problem should be addressed swiftly. This is exemplified by the United States' existing building stock, which constitutes 40% of national energy consumption and 70% within major cities (Campbell & Calhoun, 2016). This evidence not only highlights the existence of national problems in the US but also signifies the role that developed countries must play in creating globally applicable retrofitting strategies.

Navigating through the current energy dilemma, we identify potential solutions from countries like Italy, which has been successful in researching innovative solutions to tackle retrofitting challenges. As a country with around 60% of its existing buildings over 100 years old (Pianigiani & Povoledo, 2016), Italy has addressed retrofitting challenges before. With a large portfolio of experience in retrofitting, Italy could prove to be a great example of how other countries shape their energy codes and implement strong strategies to update existing buildings. A focused study of the U.S., especially a building on a campus committed to reducing its carbon footprint (as indicated by WPI's GreenHouse Gas Reduction Plan), will allow for a useful comparison. This comparative analysis might point toward a way to align U.S. energy goals with lessons learned from a leader in historic retrofitting, providing innovative, globally relevant energy and climate solutions.

Design Statement and Scope

In the face of the global climate crisis, the building sector, particularly existing buildings, stands as a major factor. To mitigate this, our goals and objectives are outlined as follows:

Goal: To design, simulate, and compare retrofitting strategies within Northeast America and Northern Italy, demonstrating differences in strategies through an exploration of regional standards and energy goals.

- Objective 1: Understand the prevailing code requirements for retrofitting existing buildings in Worcester, U.S. as well as Lecco, Italy, focusing on advancements in energy efficiency and compliance with modern standards while also researching common retrofit strategies for both locations.

- Objective 2: Identify and research a comparable building in Worcester, US, and Lecco, Italy, focusing specifically on Stratton Hall and Building 12.
- Objective 3: Develop accurate models of both identified buildings, reflecting their current energy efficiency conditions and architectural properties.
- Objective 4: Design retrofitting solutions tailored to each building with a focus on meeting code requirements, exceeding requirements, and creating a Net Zero building.
- Objective 5: Synthesize the findings to propose informed recommendations aimed at discovering shortcomings in energy codes and retrofitting strategies, fostering universally usable sustainable practices.

To begin our project, we will focus on retrofitting two buildings: Stratton Hall, an outdated, historic building situated on campus, and Building 12, a newly renovated, but imperfect building of similar attributes in Lecco, Italy. The retrofit process will encompass compliance with current energy codes through the modernization of heating and cooling systems, building envelopes, and lighting systems.

The end goal of these efforts will be to compare the strategies used by the US and Italy in refurbishing historic buildings for modern comfort. We intend to conceptualize and evaluate retrofitting strategies for each country. These strategies will analyze retrofitting to meet the prevailing code, cutting energy consumption by half, and achieving a building with net zero energy consumption.

Post-design, we'll apply each country's retrofitting strategies and analyze the end states. This evaluation will highlight the positives and potential pitfalls of each approach. Through this assessment, we aim to identify the most advantageous strategies for retrofitting, paving the way for a more sustainable and energy-efficient future for the building sector.

Methodology

In the following sections we discuss our methods for addressing each of these objectives.

Objective 1: Understand the prevailing code requirements for retrofitting existing buildings in Worcester, U.S. as well as Lecco, Italy, focusing on advancements in energy efficiency and compliance with modern standards while also researching common retrofit strategies for both locations.

It is essential that we first understand the energy codes from both regions to get a base understanding of energy efficiency requirements to use retrofit strategies that, at minimum, meet these requirements. We first began by examining energy codes at three levels: national, regional, and local. This research focused on the U-Value requirements for building walls, windows, roofs, and floors to find the most stringent requirements in each location. This included mapping the changes through the many editions of applicable codes to understand what areas the code has become increasingly more stringent in order to identify trends that would allow us to know what areas are the most important to improve.

With this information in mind, we began our research using academic articles to find the best retrofitting practices in each region. This involved investigating case studies and supporting evidence to display what strategies are the most effective. This allows us to have an idea of possible ways to improve the energy efficiency of a building through retrofitting without disturbing the exterior facade.

A summarized methodology for Objective 1:

- Research the IECC, Massachusetts state code, and local Worcester code to find the most stringent requirements for retrofitting walls, windows, roofs, and floors based on U-Value (1/R-value).
- Research the EU codes, Italian codes, and local Lecco codes to find the most stringent requirements for retrofitting walls, windows, roofs, and floors based on U-Value.
- Map the changes to the codes through the years to see trends that show what areas of buildings have become increasingly stringent to understand what to focus on when retrofitting.
- Research the best retrofitting strategies by location through academic publishings to determine the best fitting practice for each case study building.

Objective 2: Identify and research a comparable building in Worcester, US, and Lecco, Italy, focusing specifically on Stratton Hall and its counterpart.

After getting a base understanding of code and retrofitting strategies, we needed to find case studies in both Worcester and Lecco that shared similar attributes so that the work we complete on both can be comparable from beginning to end. They both needed to be built around the early 1900s, be in need of a retrofit to meet code standards, be made of similar building materials, be close in size and window to wall ratio (WWR), and have similar activity and Energy Use Intensity (EUI). To accomplish this we first started in Worcester by researching buildings built during that time period. We searched databases showing current renovation projects that focused on larger scale buildings used either academically or residentially. With an identified building in Worcester first, it would make finding a comparable building in Lecco easier. Once both case study buildings have been identified, we needed to not only understand the architecture and construction of both buildings, but we needed a comprehensive history of each building to have an overall understanding of the development of the building to be knowledgeable on the current state that they are in.

A summarized methodology for Objective 2:

- Find a building in Worcester, MA built around the 1900s that is in need of renovation and needs to meet the newest code requirements by retrofitting.
- Research the background and history of the building to understand the materials and construction methods.
- Find a comparable building in Locco, Italy based on time period, EUI, area, and WWR.
- Research the background and history of the building to understand the materials and construction methods.

Objective 3: Develop models of both identified buildings, reflecting their current energy efficiency conditions and architectural properties.

The identification of case studies allows us to create energy models in Energy Plus Design Builder of both buildings to the highest level of accuracy possible in architectural properties as well as energy efficiency performance. We used archived drawing sets as well as current project engineers, architects and a site walk to confirm the makeup of the walls, windows, roofs, and floors, the current HVAC systems, and the overall EUI of the buildings to allow us to input this data into Design Builder to replicate the current status of each building. This involved interviews with knowledgeable representatives of each building and gaining access to drawing sets that show section cuts and materials throughout the buildings.

A summarized methodology for Objective 3:

- Using the previous research of the buildings, create energy models to replicate the buildings and their EUI.

Objective 4: Design retrofitting solutions tailored to each building with a focus on meeting code requirements, exceeding requirements, and creating a Net Zero building.

Using the research from objective 1, we identified the best practices for retrofitting buildings in each region focusing on strategies that have the largest effect on overall building EUI. Then, we took our findings and implemented them into Design Builder to run EUI simulations and record data on what strategies work best for our buildings in particular. We then were able to map our data to identify which strategies are the most effective in lowering EUI. The strategies we focused on were insulation, window performance, electricity and lighting usage, HVAC, and sustainable practices. In addition to building simulation modeling we used the program THERM to better understand where our design was flawed in terms of heat transfer. We were able to compare windows, wall makeup, insulation thickness and other factors so that we met energy code requirements.

A summarized methodology for Objective 4:

- Using previous research and knowledge, analyze which strategies have the most effect on EUI.
- Apply the most effective retrofitting strategies to the energy models to lower the EUI of the buildings.
- Use THERM to better understand the heat transfer through our designed elements and propose solutions based on the results.
- Use THERM to more accurately calculate the U-Value through walls, windows, roofs and floors.

Objective 5: Synthesize the findings to propose informed recommendations aimed at discovering shortcomings in energy codes and retrofitting strategies, fostering universally usable sustainable practices.

At this point, with both buildings modeled and retrofitted, we are able to compare our findings between each building. This required us to look at the overall resulting EUI from where the building started and what materials were used to complete the retrofitting process. We compared these results and if each result would have been successful in the opposite location by implementing the strategies in the opposite model.

A summarized methodology for Objective 5:

- With all the information gathered we are now able to compare the two buildings to provide recommendations for US and Italian energy strategies and code creation.

Background

Stratton Hall

History

Local

Worcester, MA emerged as a manufacturing hub over 150 years ago. By the 1850s, Worcester had established itself as a central part of the regional rail system, earning the city the name Heart of the Commonwealth (Facts about Worcester, 2020). This was followed by rapid industrial growth, specifically in the textile industry. The city's infrastructure tells tales of its past: from buildings highlighting the design aesthetics of English textile mills to diverse architecture that once served as homes and recreation centers for its large immigrant population. Industrialists, keen on promoting a holistic growth ecosystem, not only constructed factories but also built communities around them, ensuring that the workforce had access to essential amenities (Facts about Worcester, 2020).

Today, Worcester's identity remains tied to its manufacturing past, continuing to provide employment to thousands. While the city cherishes its industrial history, it looks forward to a modern tomorrow, aiming to reinforce its reputation as a hub of innovation. With the many colleges and universities it supports, Worcester aims to continue to innovate through the forward progress that schools bring to a city.

Building

Built in 1894 with funds from the Commonwealth of Massachusetts, Stratton Hall was completed for Worcester Polytechnic Institute as it continued to expand its campus. Named after Charles G. Stratton, a WPI Class of 1875 alumnus who served as a trustee and president of the Alumni Association as well as the Mechanical Engineering Department head until 1942 (WPI Tech Bible). The building housed Navy seamen during the second world war and then was transformed into into the Department of Mathematical Sciences (Stratton Hall | Worcester Polytechnic Institute, n.d.) as it currently is today. The building is listed on the National Register District (03/05/1980) for its historical significance and is additionally listed on the State Register of Historic Places (Hall, 2023). It has proven to be a multi functional building that has undergone small changes through the years.

Building Materials

The building is a four story structure, measuring 35.4m long and 16.2m deep, and was designed by Earle and Fisher. The design resembles Salisbury Laboratories as the same architect designed both and its layout featured undivided space on the first two floors, a lecture hall and library on the third, and drawing and design rooms on the fourth (WPI Tech Bible, n.d.). It is designed in the Romanesque Revival style with uniform windows and a general rectangular shape. It is a mass masonry wall constructed with brick, brown stone, copper, limestone and granite (Davis, 1997). As a mass masonry envelope designed building Stratton Hall has seen renovations over the years to address issues, however many still exist.

Design Problems

One of the most pertinent issues that has arisen recently is the lack of energy efficiency and comfort level for its inhabitants. It was renovated in 2011, which included an upgrade of the existing wall sections to code at the time, an upgraded HVAC system on the first floor, and a new computer room (Di Vico et al., 2022). The issues that still persist, however, are that the current building is lacking in modern day energy code compliance and only the first floor provides an adequate HVAC system. The building is generally uncomfortable during warmer weather and should be considered for a retrofit to address the problems described.

Lecco Building 12

History

Local

Historically, Lecco was a fortified village strategically located at the eastern split of Lake Como and the head of the Adda River (“Lecco’s History,” 2019). This geographical position made it a vital control point for trade routes and communication pathways toward the north and across the Alps. The importance of Lecco in historical trade and communication is a testament to its long term growth, as it served as a main thoroughfare and a significant point of control.

Entering the 20th century, Lecco experienced a significant shift towards industrialization. Post-World War II, the city witnessed a surge in mechanical industries, marked by a unique combination of tradition, skilled technicians, and innovative entrepreneurship. This period was crucial for establishing the “Made in Lecco” brand, a globally recognized symbol in various industries, including high-tech sectors like aerospace (“History” 2016). From the 1990s onwards, the mechanical industry in Lecco transformed, focusing on high-value stages and pivoting towards higher quality products that were less vulnerable to economic downturns. Today, Lecco’s industries are known for their integration of advanced technology, high-quality products, and effective market engagement, all underpinned by a robust entrepreneurial culture and technical expertise.

Building

The educational landscape of Lecco is also impressive with the establishment of the Milan Polytechnic branch in the city in 1989. This institution was founded with the vision of being in close proximity to Lecco’s manufacturing sector, offering a competitive advantage in various research areas, including energy efficiency research (Milan Polytechnic, n.d.). A lesser known building on the campus is that named Building 12, which shows the revitalization of an abandoned city hospital. Originally serving as the maternity wing of the hospital, Building 12 underwent significant renovations, including upgrading its envelope, adding a vestibule, and reconfiguring its floor layout within the last decade. Despite these changes, its status as a national historic building meant that no exterior changes were permitted (G. Iannaccone, personal communication, October 23, 2023).

In terms of architecture, Building 12 is rectangular with two wings and an addition on the northwest side. This five-story building extends 62 meters in length and has depths of 21 meters at the wings and 14 meters in the middle (“Building 12 DWGs,” 2020). The preservation of its historical façade combined with modern technological upgrades show the university’s commitment to sustainable architecture.

Building Materials

Building 12 is similar in construction to many buildings built in Italy during the 19th century as it is made from typical mass stone masonry. The facade is then finished with three different claddings; stone veneer on the ground level, brick veneer on the first level and stucco on the top two levels. The rectangular shaped building is then ornamented with clean cut blocks of local stone at the sill of the windows. The building's wall did not consist of any insulation or internal systems to mitigate heat other than an interior stucco finish. The building's roof contained no insulation and consisted of a concrete slab with an attic above. This attic gave way to a pitched roof made of wood joists, decking and then shiplapped terra cotta tiles.

Design Problems

The recent renovation to the building shows the university's commitment to improving our built world. The building before the renovation faced many problems that needed addressing. The first of which was the lack of thermal insulation in the building that provided it with a large loss of energy from the use of air conditioning systems used within. Additionally the windows, doors and wall system were outdated allowing for a building to be more easily influenced by the outdoor conditions. The HVAC system as well as other technological aspects of the building such as the lights were outdated and needed to be upgraded to more efficient modern products to increase the energy performance of the building.

Code Framework

Applications In The United States

In the United States, building codes are structured hierarchically, beginning with national standards that offer guidelines for construction, safety, energy efficiency, etc. These national standards are then adopted, modified, or enhanced at the state level. Individual states often further tailor these model codes to address regional specificities, and at times, local municipalities may also introduce additional stipulations to cater to their unique needs and priorities (Sullivan, 2019). This structure has remained consistent for decades now, but a closer examination of the evolution of code is essential to gain an understanding of how they have influenced the present world.

Energy Efficiency

Code Evolution

The evolution of energy efficiency legislation in the United States, particularly concerning building construction and energy conservation, is marked by several key legislative acts and codes. This progression underscores the country's growing commitment to sustainable energy practices and reducing environmental impact.

In 1975, in response to the oil crisis, Congress passed the Energy Policy & Conservation Act. This act was pivotal in establishing the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) to set energy standards for commercial buildings. ASHRAE's role in defining and updating these standards has been crucial in ensuring that commercial buildings adhere to increasingly efficient energy use protocols.

Five years later, in 1980, the Model Energy Code (MEC) was created, extending the focus of energy efficiency from commercial to residential buildings. The MEC set a standard for residential buildings, acknowledging the importance of energy conservation across all types of construction. This initiative marked a significant expansion of the energy efficiency agenda to include the vast sector of residential construction.

The Energy Policy Act of 1992 represented a further involvement in the federal government's role in energy efficiency. Congress enacted a law requiring the Department of Energy (DOE) to be heavily involved in the development and deployment of energy codes. This involvement of the DOE was a clear indicator of the increasing importance placed on government guidance and enforcement in the realm of energy efficiency.

In a significant move in 2003, the MEC expanded and transitioned into the International Energy Conservation Code (IECC), which is still in use today. The IECC, updated every three years, reflects the dynamic nature of energy efficiency standards, adapting to evolving technologies and environmental challenges.

The Energy Policy Act of 2005 further strengthened the drive towards energy-efficient practices. Congress passed a law providing additional financial incentives for the public to pursue energy efficiency upgrades in building construction. This legislation played a critical role in promoting energy-efficient practices by making them more financially accessible to individuals and businesses.

The Climate Action Plan of 2013 was a comprehensive strategy to set new standards for power plants, advanced energy technologies, and increased renewable energy use on public lands. It aimed to enhance energy efficiency in buildings and appliances with a goal of significantly cutting carbon emissions by 2030. Additionally, the plan focused on developing fuel economy standards for heavy-duty vehicles, illustrating a broad approach to tackling energy efficiency.

Most recently, the Inflation Reduction Act of 2020 has offered significant tax credits and rebates for energy efficiency and clean energy technologies in homes and vehicles. This act includes a 30% tax credit for clean home energy systems like solar and wind, alongside substantial rebates for energy-efficient upgrades such as heat pumps. Furthermore, it incentivizes the adoption of clean vehicles, marking a comprehensive approach to promoting energy efficiency and renewable energy use. The incentives offered with these new acts will hopefully allow for the increase in both new construction and existing building projects to pursue energy efficiency goals that align with the national standards.

General

One national standard that this project will aim to address is the International Energy Conservation Code (IECC), which is dedicated to ensuring energy-efficient buildings. The IECC sets forth a comprehensive set of requirements for the effective use and conservation of energy in buildings, addressing aspects like heating and cooling, the building envelope, and lighting systems. States and municipalities adopt or adapt the IECC as a part of their local building codes, emphasizing the importance of energy efficiency in construction and renovations (Building Energy Code, 2017). The IECC is updated every 3 years to reflect the latest in technology and best practices, aiming for a more sustainable and energy-conscious built environment.

In Massachusetts, there are three levels of code: Base Code, updated every three years based on national energy code standards; Stretch Code, a stricter version adopted by the state, with cities like Worcester labeled as "Stretch Code communities" and consequently following its updates; these communities benefit from state funding for energy efficiency due to their "Green Community" designation. Lastly, there's the Specialized Code, the strictest level, aiming to achieve net-zero carbon emissions by 2050, but it doesn't apply to renovations (Sullivan, 2019). As of 2017, Worcester follows the updated Stretch Code, which equates to IECC 2021, inclusive of Massachusetts-specific and Stretch Code amendments (225 CMR 22.00 and 225 CMR 23.00), with the latter being the state's commercial code (Building Energy Code, 2017). The 225 CMR 23.00 is used primarily during the duration of this project to comply with Worcester’s stretch code.

Examining how the energy codes will influence the retrofitting of Stratton Hall the building must first be examined as a historic building since Stratton Hall is a registered historic building both nationally and at the state level. This means that any alteration of the building must comply with the Department of the Interior's Standards. This regulation allows for a preservation of historic buildings in the US, however, it comes at a cost. The Standard’s have little regard for the improvement of energy efficiency and look to instead retain the historical aspects of the building. Countless examples show the implications these outdated (1978) standards have on the modernization of historic buildings, funding for government restoration projects and influence on local regulations (Bronin, 2021).

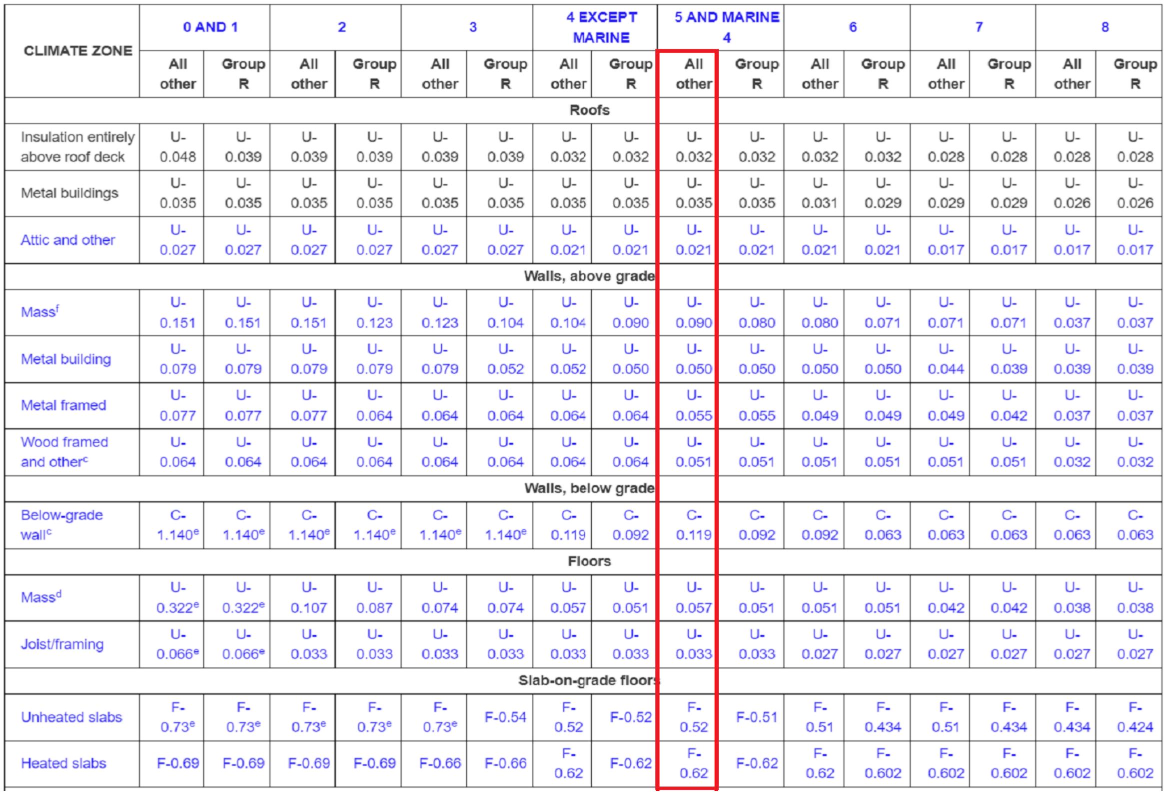
In the case of Stratton Hall approval from the local government becomes required to implement change to the building as to “not degrade the historic form, fabric or function of the building” (IECC, 2020). This approval was obtained by the facilities department (Hall, 2023) as the building is currently undergoing renovation, which in turn allows us to propose a retrofit of our own.

Building Envelope

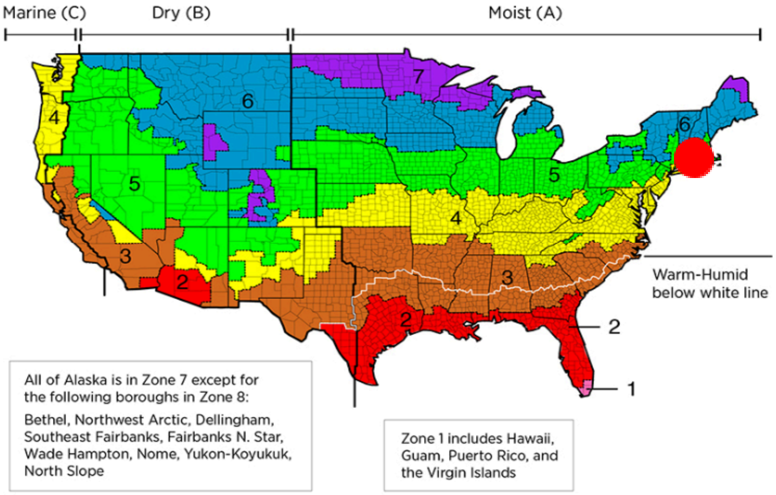
One of the most influential aspects of building retrofit projects involves upgrading the existing wall system. This can be done in many ways but at the base level the building envelope should be upgraded to meet IECC code. Per the 2021 IECC alterations to an existing building’s envelope should comply with Sections C402.1 through C402.5 which define the requirements that need to be met by a retrofit project such as Stratton Hall. These sections discuss not only fenestration thermal envelope maximums but also insulation requirements, WWR maximums, and air leakage requirements.

To begin with fenestration thermal envelope maximums, we can see that the alterations made to Stratton Hall must not allow more than 3.975 ($W/(m^2 \cdot C)$) indicating that a window analysis needs to be done. Additionally, we must investigate the envelope not consisting of fenestrations. The code contains the minimum requirements for opaque thermal envelope insulation through the U-Value method as shown in Table 1. From Table 1 and Figure 1, we can discern that the building location, marked in climate zone 5 in Figure 1, will follow the column boxed in red for each envelope system in Table 1.

Table 1: Opaque Thermal Envelope Insulation Component Maximum Requirements, U-Factor Method (IP Units)



CLIMATE ZONE	0 AND 1		2		3		4 EXCEPT MARINE		5 AND MARINE 4		6		7		8	
	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R
Roofs																
Insulation entirely above roof deck	U-0.048	U-0.039	U-0.039	U-0.039	U-0.039	U-0.039	U-0.032	U-0.032	U-0.032	U-0.032	U-0.032	U-0.032	U-0.028	U-0.028	U-0.028	U-0.028
Metal buildings	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.035	U-0.031	U-0.029	U-0.029	U-0.029	U-0.026	U-0.026
Attic and other	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.021	U-0.021	U-0.021	U-0.021	U-0.021	U-0.021	U-0.017	U-0.017	U-0.017	U-0.017
Walls, above grade																
Mass[f]	U-0.151	U-0.151	U-0.151	U-0.123	U-0.123	U-0.104	U-0.104	U-0.090	U-0.090	U-0.080	U-0.080	U-0.071	U-0.071	U-0.071	U-0.037	U-0.037
Metal building	U-0.079	U-0.079	U-0.079	U-0.079	U-0.079	U-0.052	U-0.052	U-0.050	U-0.050	U-0.050	U-0.050	U-0.050	U-0.044	U-0.039	U-0.039	U-0.039
Metal framed	U-0.077	U-0.077	U-0.077	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.055	U-0.055	U-0.049	U-0.049	U-0.049	U-0.042	U-0.037	U-0.037
Wood framed and other[c]	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.064	U-0.051	U-0.051	U-0.051	U-0.051	U-0.051	U-0.051	U-0.032	U-0.032
Walls, below grade																
Below-grade wall[c]	C-1.140[e]	C-1.140[e]	C-1.140[e]	C-1.140[e]	C-1.140[e]	C-1.140[e]	C-0.119	C-0.092	C-0.119	C-0.092	C-0.092	C-0.063	C-0.063	C-0.063	C-0.063	C-0.063
Floors																
Mass[d]	U-0.322[e]	U-0.322[e]	U-0.107	U-0.087	U-0.074	U-0.074	U-0.057	U-0.051	U-0.057	U-0.051	U-0.051	U-0.051	U-0.042	U-0.042	U-0.038	U-0.038
Joist/framing	U-0.066[e]	U-0.066[e]	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.033	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027	U-0.027
Slab-on-grade floors																
Unheated slabs	F-0.73[e]	F-0.73[e]	F-0.73[e]	F-0.73[e]	F-0.73[e]	F-0.54	F-0.52	F-0.52	F-0.52	F-0.51	F-0.51	F-0.434	F-0.51	F-0.434	F-0.434	F-0.424
Heated slabs	F-0.69	F-0.69	F-0.69	F-0.69	F-0.66	F-0.66	F-0.62	F-0.62	F-0.62	F-0.62	F-0.62	F-0.602	F-0.602	F-0.602	F-0.602	F-0.602



All of Alaska is in Zone 7 except for the following boroughs in Zone 8:
Bethel, Northwest Arctic, Dellingham, Southeast Fairbanks, Fairbanks N. Star, Wade Hampton, Nome, Yukon-Koyukuk, North Slope

Zone 1 includes Hawaii, Guam, Puerto Rico, and the Virgin Islands

Figure 1: ASHRAE 90.1 U.S. Climatic Zones

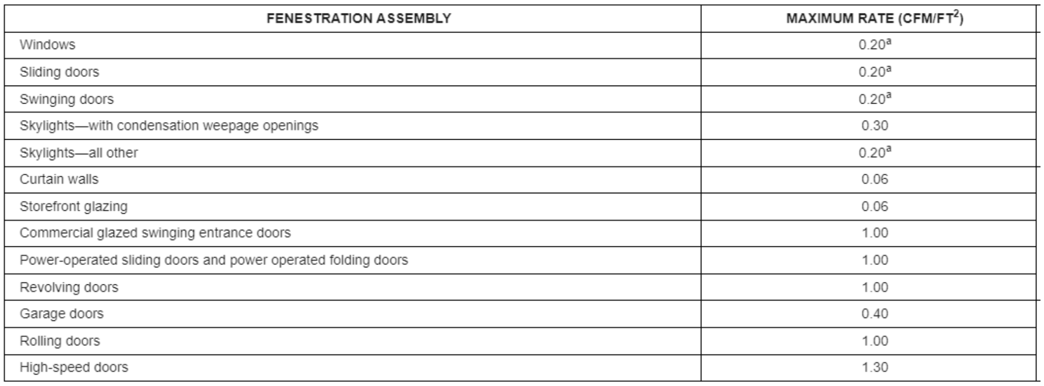
Using Table 2 we then justify what each subsection of envelope component Stratton Hall will fall under. Looking at each broad section we can determine that Stratton Hall will follow the guidelines set for: “*Roofs - Insulation entirely above roof deck*”, “*Walls, above grade - Mass*”, “*Walls, below grade - Below - grade walls*” and “*Slab-on-grade floors - Unheated slab*.” After determining which subsection the Stratton Hall retrofit must justify the numbers were converted from IP (Btu/h·ft^2·F) to SI (W/m^2·C) (in the case of *Walls, below grade* or *Slab-on-grade floors* from C factor (W/m^2·C) or F factor (W/m·C) to U factor) and then Table 2 remains.

Table 2: Opaque Thermal Envelope Maximum U-Factor Requirements for Stratton Hall

Opaque Envelope Type	**Roof**	**Walls, above grade**	**Walls, below grade**	**Slab-on-grade floors**
Subsection	*Insulation entirely above roof deck*	*Mass*	*Below - grade walls*	*Unheated slab*
Maximum U-Value	0.18	0.51	0.12	0.32

In addition to the criteria that must be met for the thermal resistance of the envelope the WWR must not exceed 30:100 unless at least 25% of the net floor area is in a daylight zone or daylight responsive controls are installed. Finally Table 3 must be met in the alteration of this building. This standard will be set by a blower door test at the end of the retrofit.

Table 3: Maximum Air Leakage Rate For Fenestration Assemblies



FENESTRATION ASSEMBLY	MAXIMUM RATE (CFM/FT^2)
Windows	0.20[a]
Sliding doors	0.20[a]
Swinging doors	0.20[a]
Skylights—with condensation weepage openings	0.30
Skylights—all other	0.20[a]
Curtain walls	0.06
Storefront glazing	0.06
Commercial glazed swinging entrance doors	1.00
Power-operated sliding doors and power operated folding doors	1.00
Revolving doors	1.00
Garage doors	0.40
Rolling doors	1.00
High-speed doors	1.30

Using Tables 1, 2, and 3 will be essential in meeting the energy codes set at the state and national level. Justifying prescriptively that our building meets codes will allow us to then further increase the energy efficiency of our building as we strive to cut the energy consumption in half and also reduce it to zero.

Heating and Cooling

Following ASHRAE Standard 90.1-2022, Energy Standard for Buildings Except Low-Rise Residential Buildings and ASHRAE Standard 100-2018, Energy Efficiency in Existing Buildings we look to upgrade the entire building's HVAC system in order to create a more energy-efficient and comfortable building. The HVAC system selected will be ASHRAE approved and Energy Star Certified, a known leader in energy-efficient certifications. The new HVAC system will also be selected based on its performance in the building model simulation.

Lighting Systems

Per the IECC alterations to an existing building shall comply with Section C405 (Electrical Power and Lighting Systems). This section highlights the need for a building such as Stratton to implement luminaries with an efficacy of not less than 45 lm/W in 90% of the permanently installed lighting systems. In addition the code requires occupancy controls on classrooms, conference rooms, restrooms, corridors, storage areas and other spaces that are less than 28 m^2. Finally, daylight controls must be used in spaces that receive limited daylight.

These requirements will prove to be important when assessing design changes that should be made in order to retrofit the building. Overall the previous sections analyzed all contribute to lowering the EUI which will prove to be the primary measure of success in the retrofit.

Energy Use Intensity

Energy Use Intensity (EUI) is a metric that measures a building's energy consumption per unit area, typically expressed as kWh/m^2/yr. This metric is both a prescriptive and performance metric that can be estimated before a building is created and measured after it has been built. Using EUI can serve as an easy way to set energy targets for a new or existing building and can act as a useful tool to lower a building's energy consumption. In the retrofit of Stratton Hall we look to use EUI as a guideline to set targets for our design. As referenced previously our goal will be to meet the Massachusetts stretch code, reduce our energy consumption by half and cut our energy consumption to zero through an EUI analysis.

Per ASHRAE Standard 100 - 2018 we are targeting an EUI of 246 kWh/m²/yr for existing college/university buildings in climate zone 5A. This would allow our project to meet the criteria set by the stretch code.

Next we look to reduce our energy consumption further by cutting it in half. Per the Greenhouse Gas Reduction Plan the EUI of Stratton Hall from an audit done in 2017 by WPI shows the building at an EUI of 344 kWh/m²/yr. Using this audit we are able to determine that our next milestone will be met by reducing the EUI to 172 kWh/m²/yr.

Finally we look towards retrofitting Statton Hall into a net zero building. This would require either a negative or 0 EUI and would mean integrating solar photovoltaics into the design. Looking at IECC Section CC101 we can learn that a path of compliance can be achieved through following the requirements of ANSI/ASHRAE/IESNA 90.1. This would allow for building energy to be determined from energy simulations as stated by Section CC103.1. Using this we can dive into using energy simulations to build an accurate model of Stratton Hall and achieve a net zero retrofit.

Analyzing all three goals we are able to determine that each goal should be approached in different ways. The path to compliance for our first goal should be achieved through prescriptive measures, while our last two goals should be achieved through a combination of prescriptive and performance measures. Using ASHRAE's Standard 90.1 - 2022 guidelines, EUI is measured by a qualified individual using as per Section 5.2. If a building's measured EUI matches or is below the target, it's compliant. If not, an energy auditor must conduct an audit, implementing Energy Efficiency Measures (EEMs) to meet the target EUI for conditional compliance. Within 15 months, compliance must be reanalyzed, proving that a year's energy use maintains adherence to the target EUI.

Renewable Energy

Renewable energy is a modern sustainable approach to energy production that focuses on harnessing natural and sustainable sources such as wind, solar, geothermal, and hydroelectricity, among others, instead of relying on fossil fuels or nuclear energy (Renewable Energy Portfolio Standard, 2019). Renewable Portfolio Standards (RPS) or Renewable Electricity Standards (RES) play a pivotal role in the shift away from fossil fuels. These are state-level policies crafted to amplify the use of Renewable Energy Sources (RES) for electricity generation. The fundamental premise is either to require or to encourage electricity suppliers to source a specified percentage of their electricity from renewable resources (Renewable Energy Portfolio Standard, 2019).

Although there's no federal RPS in effect, the U.S. has made significant strides at the state level, with the majority of states having their RPS programs (Renewable Energy Portfolio Standard, 2019). These programs are characterized by their diversity in structure, enforcement, size, and application. For instance, while some states might emphasize large utilities, others could apply standards universally to all utilities. In these state RPS programs, there's often a stipulated minimum percentage of electricity that has to be generated from renewable resources by a designated date. Notably, as of November 2022, 36 states and the District of Columbia have set RPS or analogous renewable energy goals. An ambitious goal set by 12 of these states, including D.C., is to achieve 100% clean electricity by 2050 or even sooner (Renewable Energy Portfolio Standard, 2019).

The RPS framework, provided by National Renewable Energy Laboratory (NREL), offers many resources, aligning seamlessly with federal tax credits and other policies, to galvanize renewable energy projects (Renewable Portfolio Standards, 2013). In Massachusetts the state created a RPS program in 1997 aimed at a requirement of Class I RES to fulfill 35% of the state's electricity production by 2030 and an additional 1% each year after. In addition they aimed at Class II RES to make up 6.7% by 2020. These goals were one of the first strong steps towards making Massachusetts and thus the US less reliant on fossil fuels for the future.

Applications In Italy

In Italy, building codes are structured hierarchically, beginning with European guidelines created by the European Union (EU) that offer broad guidance for its member states in construction, safety, energy efficiency, etc. These guidelines then are used to create national plans that reflect the goals set by the EU. These plans are adopted at the member state or country level once approved and can often differ in stringency between member states. In Italy national standards are created to set some specific guidelines for the regions, however much of the technical standards and enforcement of such are done at the regional level. These regions further tailor the national standards, goals and technical definitions to address regional specificities, and at times, local municipalities may also introduce additional stipulations to cater to their unique needs and priorities.

Energy Efficiency

Code Evolution

To better understand the Italian code framework it is necessary to understand the broader EU's goals and objectives over the last half a century. The evolution of their approach to energy efficiency in the building sector, is embodied through its series of directives. These directives represent a significant commitment to environmental sustainability and energy conservation by the continent and thus Italy in hand.

The journey began with a response to the oil crisis of 1975. The EU released a Council Resolution that reached a resolution promoting energy savings as a priority to deter the impacts of the crisis. In 1986 a Council Resolution emphasized the EU's need for solutions to energy and the environment. It stated that the continent needed to make use of the best available and economically justified technologies to improve energy efficiency. Less than 10 years later the 1992 Boiler Directive was the first directive that showed the international community the continent was committed to energy savings and carbon reduction. The "Boiler Directive" created the first energy efficiency directive targeted at combating climate change. In 1993 the SAVE Directive enacted by the EU required Member States to draw up and implement programs to improve energy efficiency, with the aim to limit CO2 emissions. The directive lacked strong objectives for the member states and rather gave them ambiguous goals to meet with no strong backing direction.

To address the lack of clear direction for the member states Directive 2002/91/EU, was approved on December 16, 2002, and enacted on January 4, 2003. This directive marked the EU's first major legislative effort to address energy performance in buildings. It required member states to strengthen their building regulations within three years, introducing Energy Performance Certificates (EPCs) and mandating renovations to meet Minimum Energy Performance (MEP) standards as far as technically and economically feasible. This directive laid the groundwork for a standardized approach to measuring and improving the energy performance of buildings across Europe ("Directive 2002/91/EU," 2002).

Building on this foundation, Directive 2010/31/EU, known as the "EPBD Recast," was approved on May 19, 2010, and came into force on June 18, 2010. It broadened the scope to focus on Nearly Zero Energy Buildings (nZEBs), setting more stringent energy performance requirements. This directive mandated the display of EPCs in property advertisements and established inspection schemes for HVAC systems. A significant deadline was set for all new buildings to achieve nZEB status by December 31, 2020, with an earlier deadline for public buildings. However, the directive faced challenges, as noted by Salvalai et al. (2015), who observed a high variation in nZEB definitions among member states, indicating a need for more precise and consistent guidance ("Directive 2010/31/EU," 2010; Salvalai et al., 2015).

In parallel, Directive 2012/27/EU, issued on October 25, 2012, required EU countries to draft national energy efficiency plans every three years and report their progress annually. This directive aimed to streamline the efforts of member states in achieving energy efficiency targets. To assist in this process, the Commission released a guidance document (SWD (2013) 180) providing a template for the national energy efficiency action plans ("Directive 2012/27/EU," 2012).

Furthering these efforts, the "Renovation Wave for Europe" strategy, launched in 2020, aimed to double annual energy renovation rates over the next decade. This strategy focused on three key areas: addressing energy poverty and the worst-performing buildings, improving public buildings and social infrastructure, and decarbonizing heating and cooling systems. The Renovation Wave strategy was not only about reducing emissions but also about enhancing the quality of life for residents and creating green jobs in the construction sector ("A Renovation Wave for Europe," 2020).

Directive 2018/844/EU, part of the "Clean Energy For All Europeans" package, was proposed on November 30, 2016. This directive emphasized long-term renovation strategies, incorporating information communication and smart technologies to ensure efficient building operations. It introduced Building Automation and Control (BAC) systems as alternatives to physical inspections and promoted the use of energy from renewable sources in building renovations. The directive also linked public funding more strongly to building renovations and EPCs, incentivizing efforts to tackle energy poverty ("Proposal for a DIRECTIVE," 2016).

The latest proposal, the revision of the Energy Performance of Buildings Directive (EPBD) (COM(2021)0802), was proposed by the European Commission on December 15, 2021. It is part of the European Green Deal Package and the 2030 Climate Target Plan. The revision aims for a 60% emission reduction by 2030 and achieving climate neutrality by 2050. This proposal includes the introduction of more reliable, quality, and digitized EPCs, with energy performance classes based on common criteria to create a more harmonized approach to building renovation across the EU. The proposal also suggests the gradual introduction of MEP standards to trigger renovations of the worst-performing buildings. This directive represents the latest step in the EU's ongoing journey towards a more sustainable and energy-efficient built environment ("Energy Performance of Buildings Directive," 2023; "European Commission," 2022).

The chronological development of these EU directives and strategies reflects a deepening commitment to energy efficiency, sustainable building practices, and the overall reduction of carbon emissions. Each directive builds upon its predecessors, creating a comprehensive and evolving framework aimed at transforming the European building stock into a more energy-efficient and environmentally friendly asset.

The framework for energy efficiency in building codes in Italy is complex and has evolved significantly over time, guided by a series of legislative decrees and standards. This evolution reflects Italy's commitment to aligning with EU directives and enhancing energy performance in buildings.

The foundation for implementing the EPBD in Italy was laid by the Legislative Decree 192/2005, as amended by Legislative Decree 311/2006. These decrees set the initial standards for energy performance in buildings, including guidelines for EPCs and inspections. This foundation was further reinforced by Law 90/2013, which implemented Directive 2010/31/EU, significantly altering the initial 2005 implementation of energy performance legislation ("Legislative Decree 192/2005 ANIT DOCUMENT - June 2020").

In response to Directive 2018/844/EU, Italy transposed the directive into national law through Decree 10.06.2020 n. 48, amending the Legislative Decree 192/2005. This latest decree is the most up-to-date legislative document concerning the energy efficiency of buildings in Italy. It includes provisions for local ordinances, building setbacks, and other local code compliance, although it does not impose further restrictions on energy efficiency ("DECRETO LEGISLATIVO 10 giugno 2020, n. 48").

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General

A crucial aspect of the Italian approach to energy efficiency is the role of regions and autonomous provinces. Italy has 21 such authorities, each with ultimate authority over energy policy, leading to diverse and complex regional implementations of the EPBD. Despite this diversity, recent legislation has significantly harmonized EPBD implementation across the country. A National Information System (SIAPE) for EPCs has been established, and a national register for the inspection of heating/cooling systems is being developed. These systems are managed at regional and provincial levels, ensuring localized oversight and database management.

The technical standards for estimating the energy performance of buildings are based on the national standard UNI/TS 11300. This standard is comprehensive, breaking down the calculation methods for determining the energy performance of buildings into several parts. These parts cover the determination of a building's thermal energy requirements for air conditioning in different seasons, the calculation of primary energy requirements for various utilities, and the determination of energy demand for elevators and escalators.

The minimum requirements for energy performance are clearly defined, focusing on specific energy needs for building envelope, heating, cooling, and domestic hot water, among other indices. These requirements are vital for ensuring that buildings comply with energy efficiency standards.

For a building, new or undergoing major renovation, to meet these minimum requirements, it must demonstrate that its specific energy needs for heating and cooling, as well as its global energy performance, are lower than those calculated for a reference building as described in the following section. This approach not only sets a benchmark for new construction projects but also ensures that renovated buildings achieve a substantial improvement in energy performance. The legislation also mandates a fixed minimum ratio of RES for new buildings.

Furthermore, recommendations for improvements are mandatory, with evidence of payback periods and class/performance, achievable through measures carried out in connection with major renovations, and measures for individual building elements or technical building systems. Experts are required to report on the feasibility and cost-effectiveness of these recommended measures, along with calculations and verifications certifying compliance of the new or renovated building with the standards. However, this report is not mandatory for minor measures, like the replacement of boilers with power less than 50 kW or replacing a traditional boiler with condensing boilers.

The qualifications for EPC experts are strictly defined under Presidential Decree 75/2013. The designer of a building project is also required to justify compliance or non-compliance of the project to MEP requirements in a report, which is a prerequisite to obtain the construction license. Controls from local authorities to check compliance are performed on demand, ensuring adherence to these stringent standards.

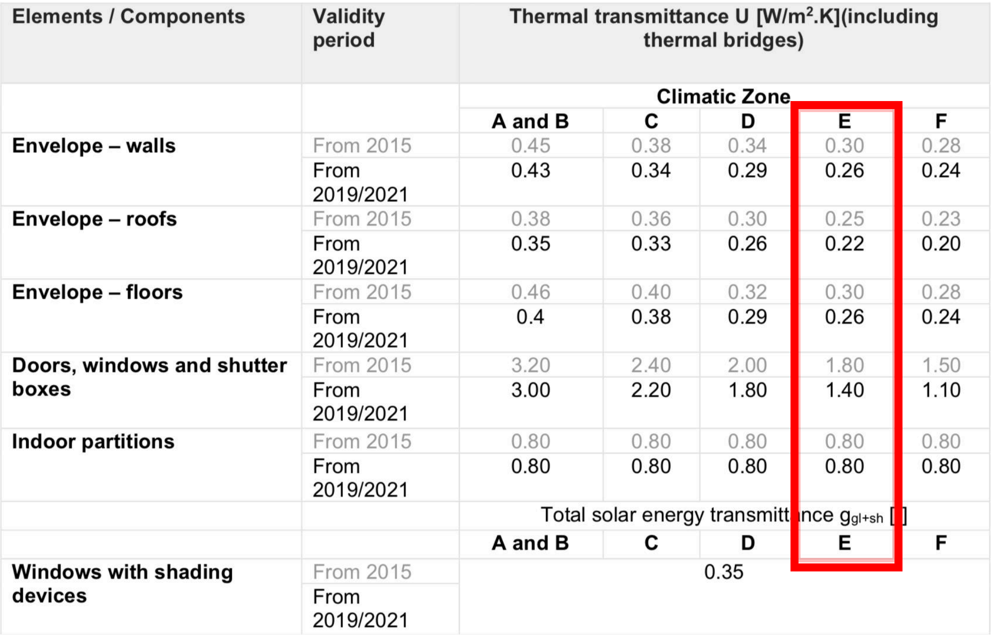
In conclusion, Italy's code framework for building energy efficiency is a comprehensive system that integrates European directives, national legislation, and technical standards. It balances the need for uniformity in energy performance across the country with the flexibility to accommodate regional differences. This framework represents Italy's robust commitment to improving energy efficiency in buildings, reducing environmental impact, and contributing to global efforts in energy conservation and sustainability.The framework for energy efficiency in building codes in Italy is complex and has evolved significantly over time, guided by a series of legislative decrees and standards. This evolution reflects Italy's commitment to aligning with EU directives and enhancing energy performance in buildings.

Building Envelope

The energy efficiency performance standards for building envelopes in Italy are regional and cater to the diverse climatic conditions across the country. These standards are crucial for new constructions and major renovations that need to meet the MEP requirements, aligning with the cost-optimal methodology established by Italy.

One of the key pathways towards compliance is to meet envelope requirements for heat resistance similar to those set in the United States. These guidelines are set at the regional level and are shown in Table 4 translated and created by the EPBD Concerted Action program.

Table 4: Opaque Thermal Envelope Maximum U-Value Requirements



Elements / Components	Validity period	Thermal transmittance U [W/m^2.K](including thermal bridges)				
		Climatic Zone				
		A and B	C	D	E	F
Envelope – walls	From 2015	0.45	0.38	0.34	0.30	0.28
	From 2019/2021	0.43	0.34	0.29	0.26	0.24
Envelope – roofs	From 2015	0.38	0.36	0.30	0.25	0.23
	From 2019/2021	0.35	0.33	0.26	0.22	0.20
Envelope – floors	From 2015	0.46	0.40	0.32	0.30	0.28
	From 2019/2021	0.4	0.38	0.29	0.26	0.24
Doors, windows and shutter boxes	From 2015	3.20	2.40	2.00	1.80	1.50
	From 2019/2021	3.00	2.20	1.80	1.40	1.10
Indoor partitions	From 2015	0.80	0.80	0.80	0.80	0.80
	From 2019/2021	0.80	0.80	0.80	0.80	0.80
		Total solar energy transmittance g_{gl+sh} [ ]				
		A and B	C	D	E	F
Windows with shading devices	From 2015	0.35				
	From 2019/2021					

From Table 4 and the climate zone map shown in Figure 2, we can discern that the building location, marked in climate zone E, will follow the column boxed in red for each envelope system.

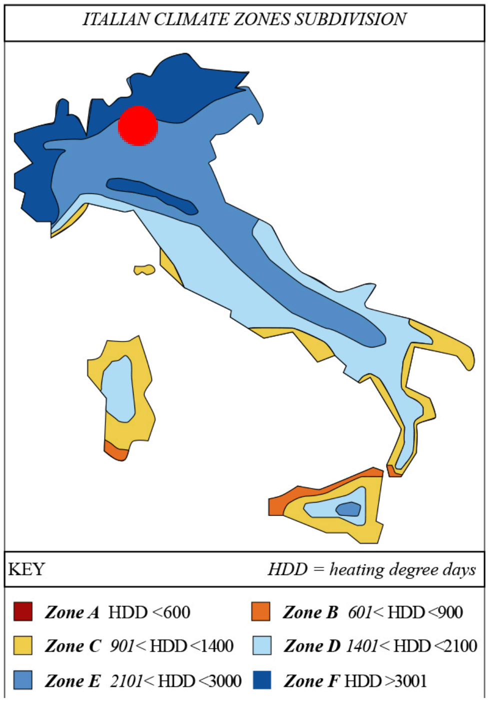


Figure 2: Italian Climate Zones Subdivision

After examining Table 4, the climate zone map and the climate zone indicator website found in Appendix A we can break down the requirements that will be used for Building 12 in Lecco and simplify Table 5 to the following.

Table 5: Opaque Thermal Envelope Maximum U-Factor Requirements for Building 12

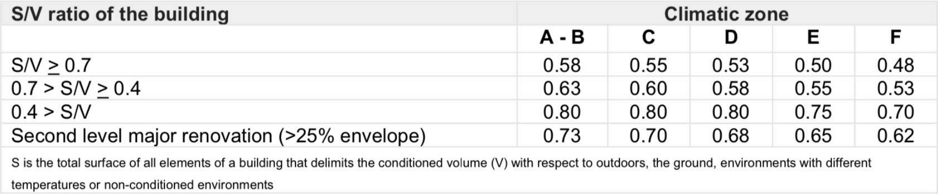
Opaque Envelope Type	**Envelope - walls**	**Envelope - roofs**	**Envelope - floors**	**Doors, windows and shutter boxes**	**Indoor partitions**
Maximum U-Value ($W/m^2 \cdot C$)	0.26	0.22	0.26	1.4	0.8

In parallel to prescriptively meeting MEP envelope requirements a building's overall performance must align with the criteria set forth for a reference building. This reference building is a model with predefined thermal characteristics and energy parameters, identical in geometry, orientation, location, and use to the actual building in question, situated in a comparable environment.

This reference building is used in comparison to the design proposal and once each of the following parameters described below are met the designed building in question will be allowed to begin work. This path of compliance is used in an overwhelming number of situations and is provided through a governmentally authorized free or paid software. These softwares are limited in language capability, however, and are not available in English.

To begin examining the parameters the proposed building must meet we start with the mean transmission heat transfer coefficient, denoted as H'_T ($W/m^2 \cdot C$). It must fall below the prescribed limit for the building's climatic zone and its surface-area-to-volume ratio (S/V) as shown in Table 6.

Table 6: H'_T Maximum Limit Value



S/V ratio of the building	Climatic zone				
	A - B	C	D	E	F
$S/V \geq 0.7$	0.58	0.55	0.53	0.50	0.48
$0.7 > S/V \geq 0.4$	0.63	0.60	0.58	0.55	0.53
$0.4 > S/V$	0.80	0.80	0.80	0.75	0.70
Second level major renovation (>25% envelope)	0.73	0.70	0.68	0.65	0.62

S is the total surface of all elements of a building that delimits the conditioned volume (V) with respect to outdoors, the ground, environments with different temperatures or non-conditioned environments

For instance, the city of Lecco, which falls within climatic zone E, would adhere to the limits indicated for that specific zone. These H'_T values are calculated based on the initial design proposals.

Additionally, the ratio of the summer effective collecting area of the transparent components to the net floor area must also meet set limits for both residential and non-residential buildings as shown in Table 7.

Table 7: $A_{sol,est}/A_{sup,utile}$ Maximum Limit Value

Building categories	All climatic zones
Residential buildings	≤ 0.030
Non-residential buildings	≤ 0.040

The exact methodology for determining this ratio involves calculations that account for the size and orientation of transparent elements like windows in relation to the overall floor area of the building.

Furthermore, the mass of the external walls (on all sides except northeast to northwest) must exceed 230 kg/m², or alternatively, their periodic thermal transmittance YIE must be lower than 0.12 W/m²·K, as defined in EN ISO 13786. The periodic thermal transmittance YIE for roofs and floors is also capped, with a requirement to be lower than 0.18 W/m²·K. These transmittance values are indicative of the building's capacity to manage heat transfer, which directly impacts energy consumption for heating and cooling.

These stringent MEP requirements are part of Italy's broader strategy to reduce energy consumption in buildings and promote sustainability within the construction sector. Through adherence to these region-specific standards, Italy aims to decrease overall energy usage and contribute to a more energy-efficient future.

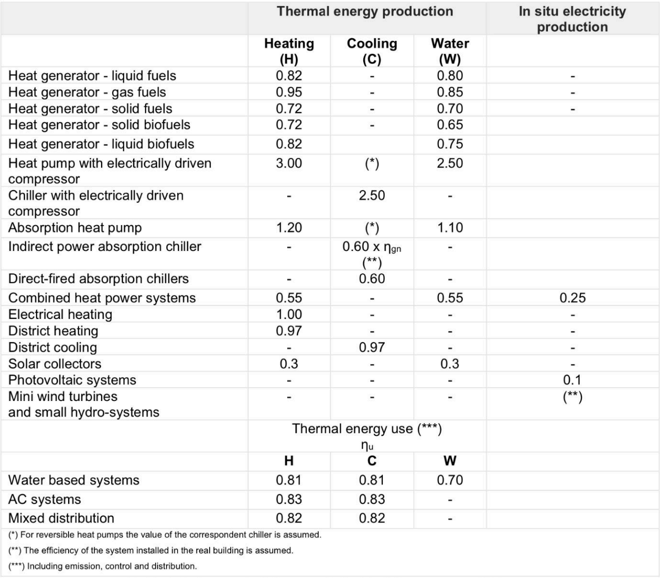
Heating and Cooling

The 2010/31/EU Directive, also known as the EPBD Recast, mandated EU member states to establish and implement inspection schemes for heating and air-conditioning systems. These schemes are part of a broader strategy to reduce energy consumption and improve the energy performance of buildings throughout the EU. The directive aimed to encourage energy savings by ensuring that heating and cooling systems operate efficiently, which is crucial for the overall energy performance of a building ("DIRECTIVE 2010/31/EU," 2010).

To comply with the EPBD, member states must also have independent control systems in place for EPCs and inspection reports. These systems are designed to verify the accuracy and reliability of the energy performance documentation that building owners are required to obtain. By establishing such controls, the directive ensures that EPCs and inspection reports for heating and cooling systems are not only issued in accordance with the relevant procedures but also provide a true reflection of the buildings' energy performance.

In Italy the standard states that for new buildings and existing buildings undergoing renovations that effectively render them as new in terms of energy performance, the mean efficiencies of the technical building systems must surpass those of a reference building. The mean efficiencies for heating (ηH), cooling (ηC), and domestic hot water (ηW) systems must be higher than the corresponding efficiencies calculated for this reference building as shown in Table 8.

Table 8: Mechanical Systems Minimum Efficiency



	Thermal energy production			In situ electricity production
	Heating (H)	**Cooling (C)**	**Water (W)**	
Heat generator - liquid fuels	0.82	-	0.80	-
Heat generator - gas fuels	0.95	-	0.85	-
Heat generator - solid fuels	0.72	-	0.70	-
Heat generator - solid biofuels	0.72	-	0.65	
Heat generator - liquid biofuels	0.82		0.75	
Heat pump with electrically driven compressor	3.00	(*)	2.50	
Chiller with electrically driven compressor	-	2.50	-	
Absorption heat pump	1.20	(*)	1.10	
Indirect power absorption chiller	-	0.60 x η_{gn} (**)	-	
Direct-fired absorption chillers	-	0.60	-	
Combined heat power systems	0.55	-	0.55	0.25
Electrical heating	1.00	-	-	-
District heating	0.97	-	-	-
District cooling	-	0.97	-	-
Solar collectors	0.3	-	0.3	-
Photovoltaic systems	-	-	-	0.1
Mini wind turbines and small hydro-systems	-	-	-	(**)
	Thermal energy use (***) η_u			
	H	**C**	**W**	
Water based systems	0.81	0.81	0.70	
AC systems	0.83	0.83	-	
Mixed distribution	0.82	0.82	-	

(*) For reversible heat pumps the value of the correspondent chiller is assumed.

(**) The efficiency of the system installed in the real building is assumed.

(***) Including emission, control and distribution.

By following these standards the retrofit design aims at aligning itself with the goals of the EU and the goals of Italy in reducing energy consumption through not only the envelope design but also the mechanical design of the modernized building.

Lighting Systems

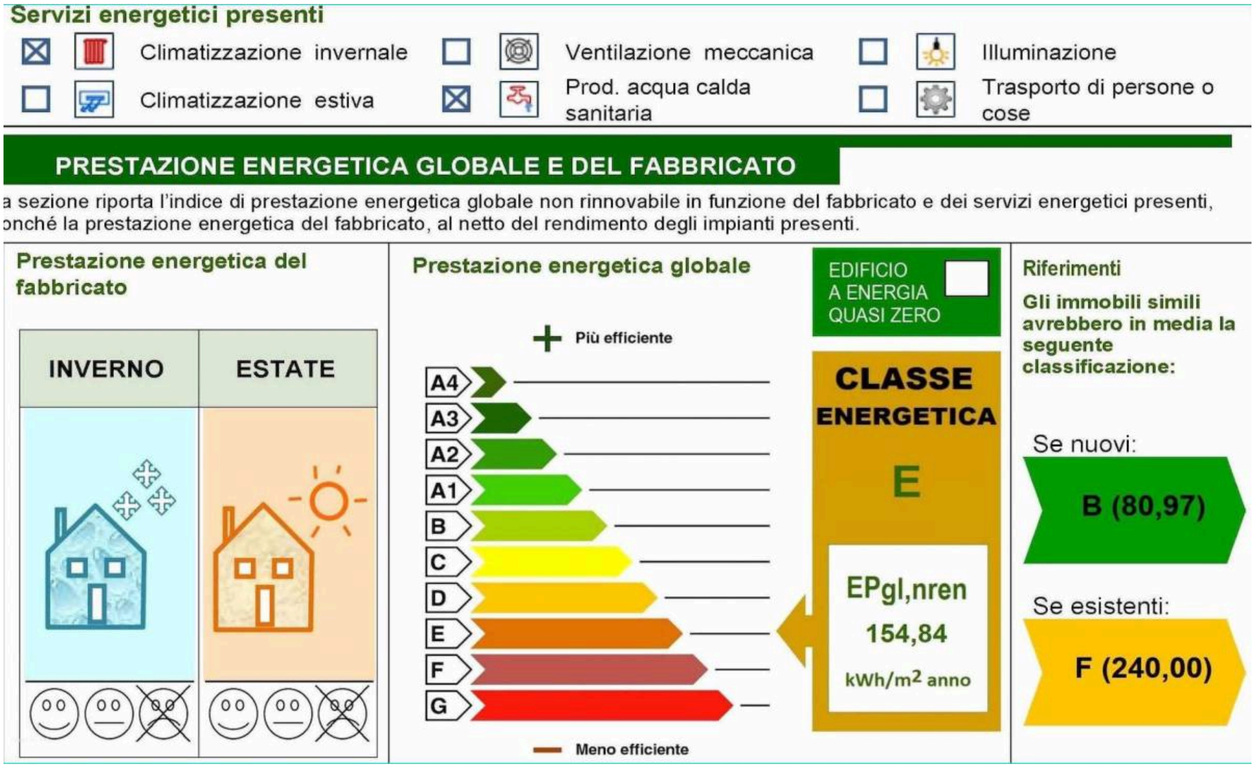
The lighting systems for the retrofit of an existing building must comply with the standards set out for the creation of a new building. All lighting systems or individual lighting replacement must meet the minimum requirements set out by the ISO/CIE 20086:2019 standards established by the International Standards Organizations (ISO) (“Light and Lighting — Energy Performance of Lighting in Buildings”). For the case of Building 12 this means that the Lighting Energy Numeric Indicator (LENI) must be calculated to determine the amount of energy the lighting system consumes on a yearly basis. This number is then compared to the reference building and must be lower than the threshold set. The calculation of LENI is complex and is completed using authorized building modeling software.

Energy Use Intensity

In Italy, the concept of EUI lacks a standardized framework, diverging from the approach where specific requirements must be met for different building types. Instead, EUI serves as a comparative tool to discern the various energy classes a building could achieve. This methodology comes into play particularly during the proposal stages of a building's design, be it for new constructions or major renovations. Designers are tasked with demonstrating that their projects align with the standards of a uniquely defined reference building. The nature of this reference building is inherently situational, meaning the energy class it embodies will vary from case to case.

The primary aim behind establishing a reference building's EUI is to facilitate a thorough analysis of the building in question. This involves combining the EUI with the energy derived from renewable sources to ascertain the final energy classification of both the reference and the proposed buildings. The significance of calculating the EUI extends to the issuance of the "Attestato di Prestazione Energetica (APE)," an EPC that evaluates a building's energy consumption levels. Through the EUI of the reference building, designers alongside energy certification experts can determine the current and potential energy classes of a building's design or existing structure.

For example, using Figure 3 below consider a building that currently falls into Class F (Se esistenti) with an EUI of 240 kWh/m²/yr. However, with improvements reducing the EUI to 154.84 kWh/m²/yr, the building could ascend to Class E. Additionally, we can see on the right side that if this building was built new (Se Nuovi) it could be built to a Class B with an EUI of 80.97 kWh/m²/yr. This example underscores the EUI's role in not only benchmarking energy performance but also in charting a pathway for energy optimization and classification elevation for existing buildings.



Servizi energetici presenti

☒ Climatizzazione invernale
☐ Climatizzazione estiva
☐ Ventilazione meccanica
☒ Prod. acqua calda sanitaria
☐ Illuminazione
☐ Trasporto di persone o cose

PRESTAZIONE ENERGETICA GLOBALE E DEL FABBRICATO

a sezione riporta l’indice di prestazione energetica globale non rinnovabile in funzione del fabbricato e dei servizi energetici presenti, onché la prestazione energetica del fabbricato, al netto del rendimento degli impianti presenti.

Prestazione energetica del fabbricato

INVERNO
ESTATE

Prestazione energetica globale

Più efficiente
A4
A3
A2
A1
B
C
D
E
F
G
Meno efficiente

EDIFICIO A ENERGIA QUASI ZERO ☐

CLASSE ENERGETICA
E

EPgl,nren
154,84
kWh/m2 anno

Riferimenti

Gli immobili simili avrebbero in media la seguente classificazione:

Se nuovi:
B (80,97)

Se esistenti:
F (240,00)

Figure 3: Italian Energy Performance Certificate (EPC)

Renewable Energy

Based on the Energy 2020 strategy for competitive, sustainable and secure energy (COM/2010/0639), the EU aimed to reduce GHG emissions by at least 20%, increase the share of RES to at least 20% of consumption and achieve energy savings of 20% or more by 2020. This goal was created through national renewable action plans, which explained how each country intended to meet the goals set by the EU (“Renewable Energy Targets - European Commission”). Every 2 years between 2001 and 2018 each MS reported their progress towards these goals through a template created by the EU. This served as a EU-wide report allowing for the continent to track how the policies affected each country.

In Italy the following questions were answered every two years:

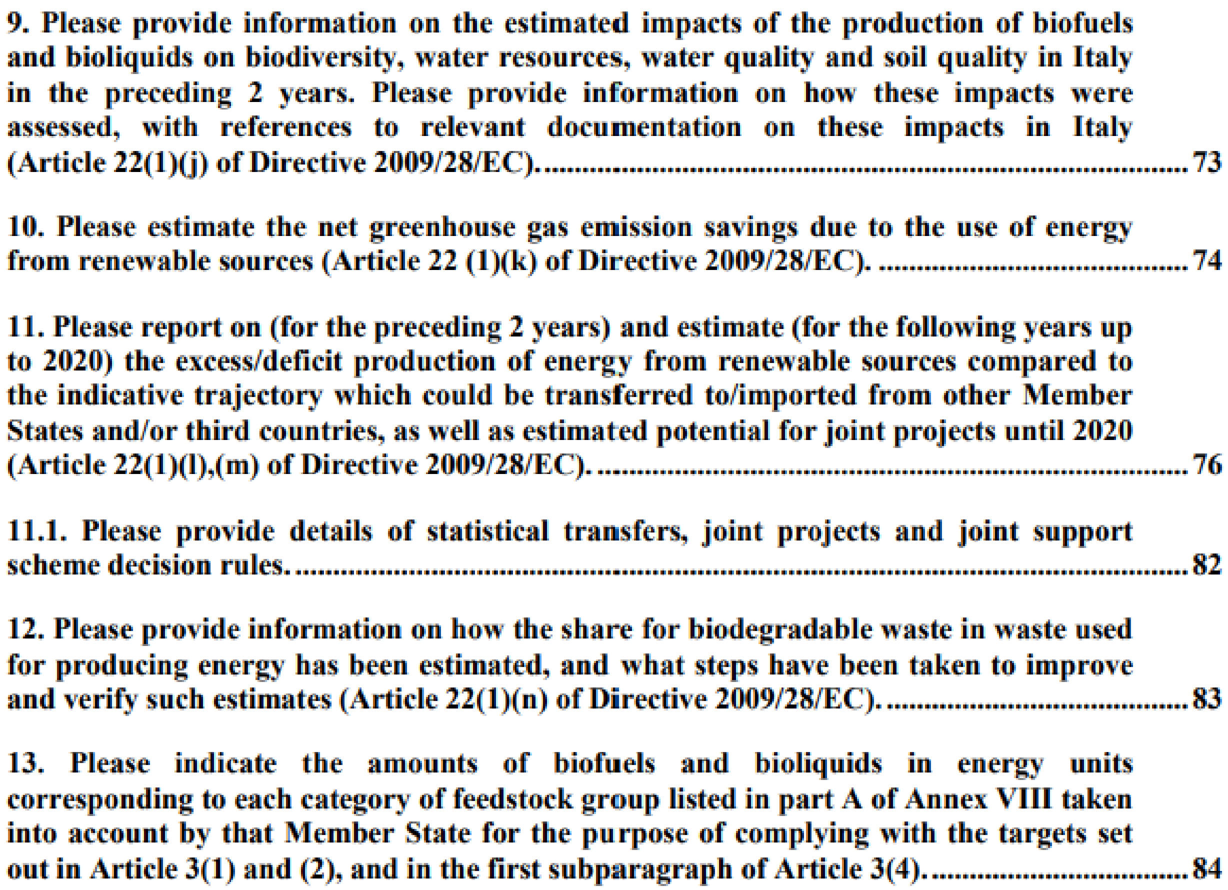


Figure 4: Italian RES Progress Report

By providing consistent tracking of the MS the EU was able to exceed their goal of 20% and reach an energy consumption share from RES of 22.1% in the year 2020.

The EU's REPowerEU Plan is a new strategy attempting to build on the successful initial plan and is aimed at enhancing energy independence by significantly reducing reliance on Russian fossil fuels, while concurrently fostering a greater transition towards RES. Central to this plan is the goal to increase the EU's renewable energy target to 45% by 2030. The plan outlines key measures including the acceleration of heat pump installations and a substantial increase in renewable hydrogen production and imports, targeting 20 million tonnes by 2030 ("REPowerEU Plan"). Furthermore, it underscores the necessity for substantial investments, quantified at €210 billion, to support these objectives and to bolster energy storage and infrastructure, ensuring energy security.

Within this framework, Italy is expected to play a crucial role by aligning national policies and investments with the REPowerEU directives, focusing on energy diversification, efficiency, and renewable integration. This includes leveraging the Recovery and Resilience Plans (RRPs) to facilitate Italy's transition towards a more sustainable and independent energy system, while also participating in cross-border initiatives to enhance the EU's collective energy infrastructure and security ("REPowerEU Plan"). Specifically Italy will continue to use measures stated in their progress report of 2019 to continue to remain on a steady path forward as they move away from fossil fuels.

Retrofitting Design

Case Studies

General

An existing issue in the world is the poor energy performance of existing buildings, especially those older than 50 years. It is well known that worldwide buildings are responsible for around 40% of total final energy consumption and one third of GHG emissions, and, despite the achieved energy efficiency gains, energy use in buildings are expected to further increase (Crespi et al., 2021). This problem has resulted in the practice of retrofitting existing buildings to improve their energy efficiency and reduce their emissions. It has been estimated that 97% of the EU building stock needs to be upgraded (Crespi et al., 2021). Large scale historic buildings are traditionally built using mass masonry, most commonly brick, to achieve their rigidity and size. Our case studies fit this profile which is the reason for our focused efforts on strategies for this construction type.

Since this issue is prevalent across Europe and the United States, many different strategies and practices have been used in an attempt to resolve this issue. This is due to the differences in common construction practices, access to certain materials, climate, etc. therefore making the standardization of retrofitting difficult. Often a retrofitting solution that works efficiently in one climate zone proves difficult to replicate as effectively in another (Crespi et al., 2021). Although the designs may differ, the philosophy behind them is all the same; energy efficiency and RES are crucial in order to decrease the carbon footprint (Crespi et al., 2021). We looked into different country case studies to get an idea of practices that we could use on our own building projects.

Each country has different benchmarks and definitions for existing building retrofitting and each one has a different energy reduction goal with no clear standardized benchmark for retrofitting. Therefore we standardized them into our own benchmark goals for retrofitting design using key performance indicators. This was done to give ourselves a comparable goal that could be applied on a building to building basis. The first benchmark was to update the existing case study buildings to meet the energy code standard most stringent in the region. This differs in each case study as the most stringent energy code for the building could be national, state wide, or local codes. The next key performance indicator was what is known as a “Deep Energy Retrofit” (DER) which is a standard certification that is achieved by reducing the energy usage by 50% through retrofitting. The final benchmark was to have a Net Zero building. Our indicator defined Net Zero as a building producing more energy than it is consuming in the form of renewable energy production. Using these key performance indicators was essential in creating standard goals for our project.

After first looking into different case studies from many locations, we produced our own designs for retrofitting our own building projects. Using Welch’s definition for designing a successful energy efficient building the following factors were considered: energy efficiency, ventilation, indoor air quality, thermal comfort, durability, affordability, and building resistance. Since both case study buildings are protected historically, the exterior facade could not change meaning that the insulation is entirely an interior endeavor (Welch et al., 2023) posing an interesting design problem. The following sections lay out the case studies researched for common retrofitting practices organized by country followed by our own resulting designs mapped out through each benchmark.

United States

According to the U.S. Energy Information Administration (EIA), the United States consumed 28.7 trillion kWh of energy in 2021(Welch et al., 2023). The standard practice targets the space conditioning load of a building by focusing on the design of insulation, airtightness, and passive design measures (Welch et al., 2023). The most common practice for insulating the interior of an existing building in the U.S. is to build a timber framed stud wall on the interior side of the masonry to then fill with insulation and sheath to create a finished surface on the interior. Another common retrofit strategy is to improve the windows and the air tightness of openings in the building. Most historic buildings were originally built with single pane windows which can be greatly improved upon. Triple pane windows, the most thermal resistant, have classically been a challenge for historic buildings, as keeping the original historic windows is often a mandatory requirement. If the original windows cannot reasonably be kept, then they are to be replaced with windows that fit the original aesthetic (Welch et al., 2023). Also, triple pane windows are harder to come by and significantly more expensive. With this in mind, a more practical practice is to use more accessible double pane windows which is still an improvement. Other common strategies in the U.S. have been left under the vague heading of “improving energy efficiency” which includes improving the HVAC system as well as the lighting system. There is no guide or aid to achieving this just that both these areas should be improved in a building. Finally, the last practice mentioned was the addition of PV panels on the roof of the building to produce renewable energy on site lowering the net energy usage.

Italy

A study in Italy looked into retrofitting a hotel in Milan using a number of different combinations of strategies (Crespi et al., 2021). The Milan hotel retrofit model can be seen in Figure 5 and started with the following parameters shown in Table 9. Envelope start: basic masonry construction with double glazed windows and minimal interior insulation depicted in the image below. System start: Gas Boiler for heating air and water (theoretical efficiency equal to 0.88), while space cooling is guaranteed using a water-cooled chiller. Four-pipe fan coils were modeled for the guestrooms, with a double circuit for hot and chilled water, to allow their simultaneous delivery, while single-duct variable air volume (VAV) systems with zonal post-heating were selected for the remaining zones.

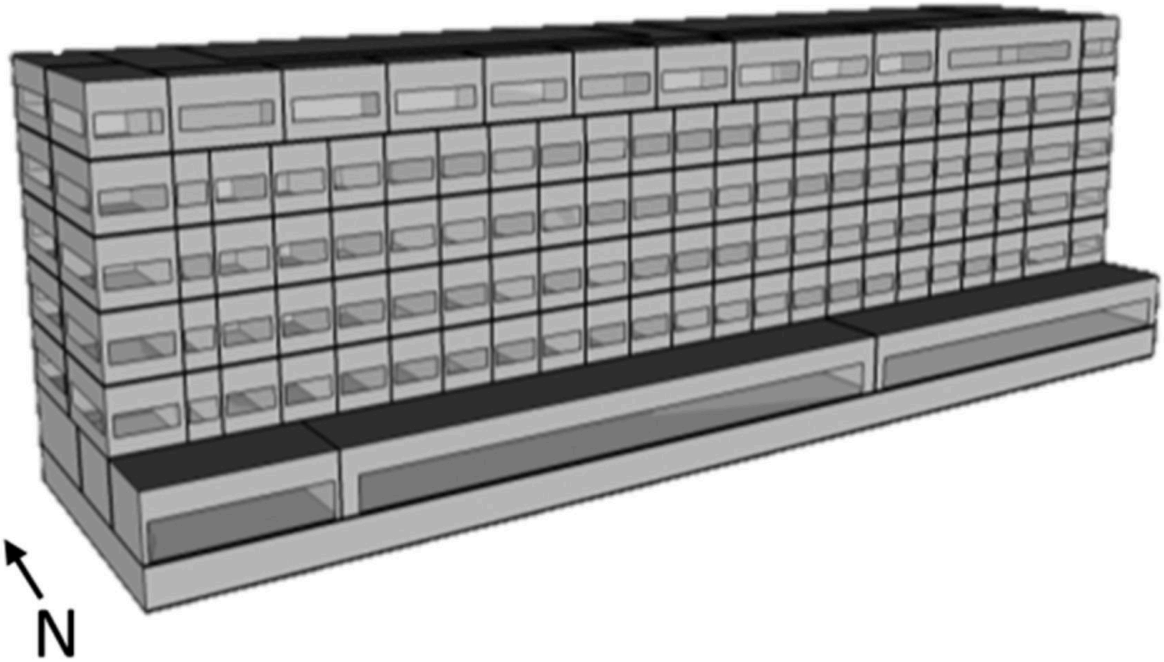
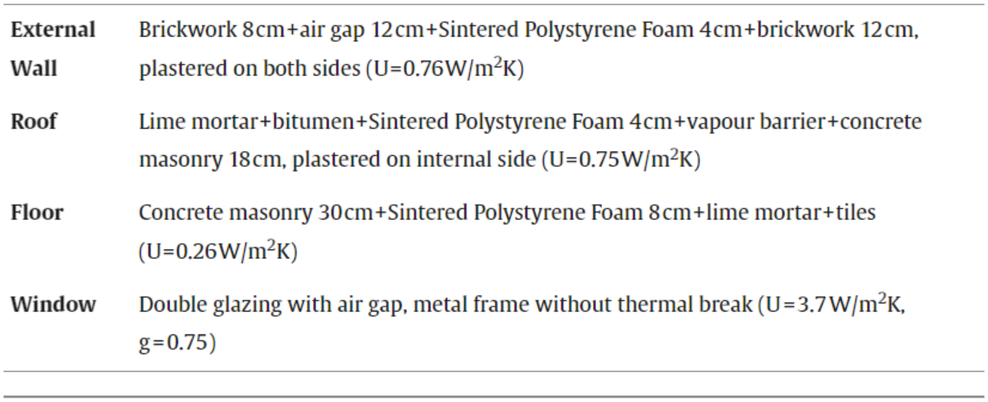


Figure 5: Milan Hotel Model

Table 9: Main envelope characteristics of Milan hotel



External Wall	Brickwork 8cm+air gap 12cm+Sintered Polystyrene Foam 4cm+brickwork 12cm, plastered on both sides (U=0.76W/m^{2}K)
Roof	Lime mortar+bitumen+Sintered Polystyrene Foam 4cm+vapour barrier+concrete masonry 18cm, plastered on internal side (U=0.75W/m^{2}K)
Floor	Concrete masonry 30cm+Sintered Polystyrene Foam 8cm+lime mortar+tiles (U=0.26W/m^{2}K)
Window	Double glazing with air gap, metal frame without thermal break (U=3.7W/m^{2}K, g=0.75)

The following is a list of the retrofit strategies:

- Envelope Retrofit Methods (ERM)
    - ERM_1 considers the addition of a thermal insulation layer of Sintered Polystyrene Foam on external walls and roof (with thermal conductivity equal to

    0.041 W/mK, and variable thickness values set according to the location: in Milan, layers of 8 cm and 11 cm were considered for external walls and roof
  - ERM_2, instead, consists in the replacement of existing windows with highly efficient ones (low-emissivity double glazing with metal frame with thermal break)
- System Retrofit Methods (SRM)
  - SRM_1 considers the substitution of the existing lighting systems with LED technology in all the thermal zones, reducing the internal gains due to the lighting systems to 3 W/m2 per each thermal zone
  - SRM_2 assumes the substitution of existing fan coils with VAV systems in the guestrooms, the installation of cross-flow plate heat recovery units in the AHUs and of better-performing boiler and chiller
  - SRM_3 considers the installation of both PV panels and solar collectors on available flat surfaces
  - SRM_4 considers the adoption of sole PV panels
  - SRM_5 assumes the connection to a district heating network
  - SRM_6, SRM_7 and SRM_8 consider the substitution of the original boiler with other heating systems. The existing chiller is used as a cooling system in all the system retrofit measures.
  - SRM_6 a condensing gas boiler (theoretical efficiency equal to 0.95)
  - SRM_7 an electrical boiler
  - SRM_8 an air-to-water heat pump

Success of the retrofit was judged on Key Performance indicators. The main indicators that were considered in picking the best strategies were annual energy consumption, annual CO2 emissions, and emission reductions which all correlate to each other. The results from combining the different strategies are shown in Figure 6 and 7. The graphs in Figure 6 and 7 are comprised of multiple different combinations of the above strategies and categorized.

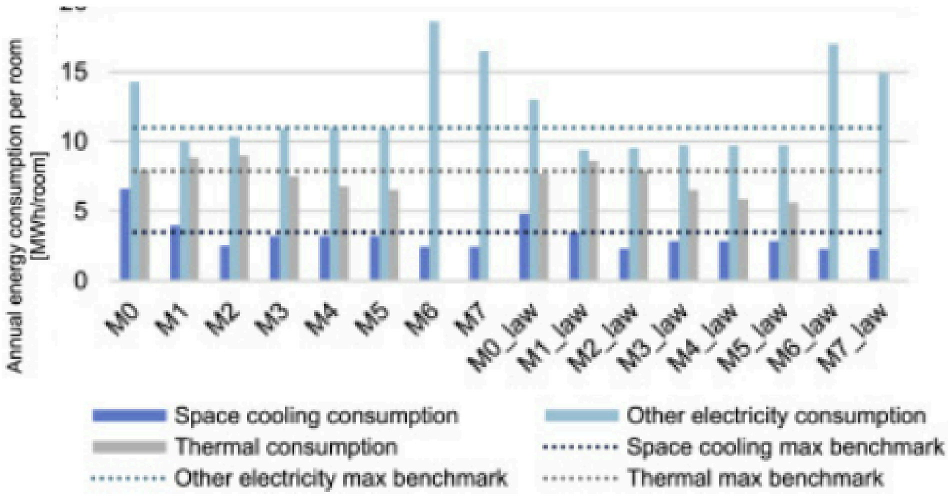


Figure 6: Annual Energy Consumption Per Room By Retrofit Strategy

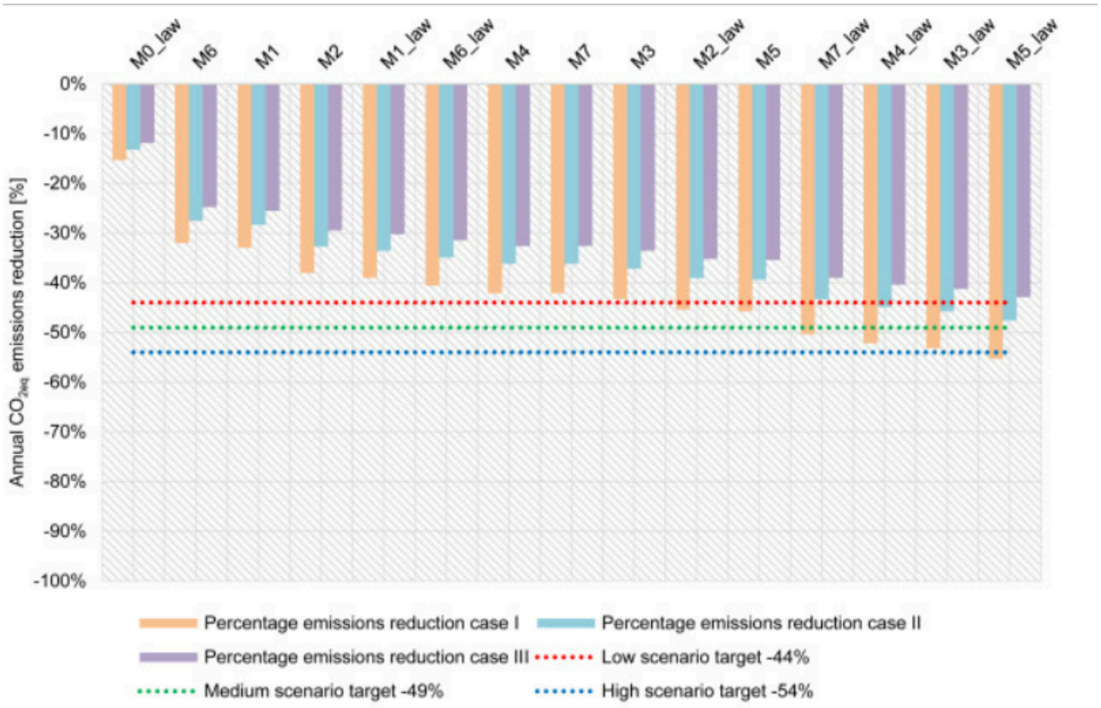


Figure 7: Annual CO2 Equivalent Emission Reduction By Retrofit Strategy

It is apparent in Figure 6 and 7 that the category “M5_Law” performs the best in efficient energy consumption and reduction of emissions. This method is comprised of the combination of the following retrofit methods:

- ERM_1 considers the addition of a thermal insulation layer of Sintered Polystyrene Foam on external walls and roof (with thermal conductivity equal to 0.041 W/mK, and variable thickness values set according to the location: in Milan, layers of 8 cm and 11 cm were considered for external walls and roof
- Upgrading windows to better performing
- ERM_2, instead, consists in the replacement of existing windows with highly efficient ones (low-emissivity double glazing with metal frame with thermal break)
- SRM_1 considers the substitution of the existing lighting systems with LED technology in all the thermal zones, reducing the internal gains due to the lighting systems to 3 W/m2 per each thermal zone
- SRM_2 assumes the substitution of existing fan coils with VAV systems in the guestrooms, the installation of cross-flow plate heat recovery units in the AHUs and of better-performing boiler and chiller
- SRM_3 considers the installation of both PV panels and solar collectors on available flat surfaces
- SRM_6 considers the substitution of the original boiler with a condensing gas boiler (theoretical efficiency equal to 0.95). The existing chiller is used as a cooling system in this retrofit measure.

As a result of this study on a hotel in Milan, these strategies together prove to be the best course of action for our own retrofitting process since our base building is at a similar starting point and in the same climate zone as this study. These strategies are further analyzed and tested on our own case study building to ensure the best fit for our building.

Portugal

The Portuguese case study building consisted of three elevated floors of residential use and the ground floor level for commercial use, with facades covered by ceramic tiles of great historical value and other external architectonic features that have to be preserved and maintained. Thus, the insulation layer has to be executed on the internal side of external walls. The thickness of granite stone walls varies from 25 cm to 65 cm, for external and partition walls. The interior floors and ceilings are in timber structure (Rodrigues et al., 2015).The Portuguese study explored internal insulation systems of varying thicknesses, thereby tackling the common concern of reduced living space due to additional interior insulation (Welch et al., 2023). It is a difficult challenge to add an effective interior insulation material without significantly reducing interior space.

In order to accomplish the Portuguese thermal requirements, two different insulation solutions of varying thickness were explored to offer options based on building interior space. Rigid XPS insulation board or Vacuum insulated Panel (VIP) (Rodrigues et al., 2015). The designer has decided to adapt 4 cm of XPS on the internal face of the stone envelope (external walls), 5 cm in the 11 cm thick brick wall between the dwellings and the staircases, and two layers with 3 cm and 5 cm of XPS in the floor above the commercial space and in the ceiling of the third floor (Rodrigues et al., 2015). Although the designer chose XPS, VIPs are the perfect solution in areas where lack of construction space or thickness is an issue. Typically, commercially available VIPs achieve a thermal conductivity of 0.004 W/(m·K) across the center of the panel, or an overall value of 0.006–0.008 W/(m·K) after allowing for thermal bridging. This means that VIPs have about one-fifth the thermal conductivity of conventional insulation, and therefore about five times the thermal resistance (R-value) per unit thickness, but are more expensive.

To improve the HVAC efficiency, a ventilation system with heat recovery (MVHR) is needed to guarantee the housing thermal comfort. The heat recovery system, composed of a compact heat pump with 80% efficiency and a storage mass integrated to produce the domestic hot water, was located in the loft, outside the thermal envelope. This central ventilation system was designed to supply fresh air into the main rooms and to extract air from kitchens and toilets, taking advantage of the cross-ventilation principle. Therefore, to optimize the ventilation system, flats were divided into two zones (supply air zone and extract air zone), maximizing the air exchange in all the compartments through the air renovation from the supply to the extract zone and avoiding the air dispersion between compartments (Rodrigues et al., 2015). Another factor that was discussed to reduce heating loads at night was the addition of an internal thermal mass to absorb heat during the day and release it at night.

United Kingdom

The Stirley farm house located in the UK is an old masonry barn retrofitted in this case study. The Stirley farmhouse focused almost entirely on the interior, utilizing a box-within- a-box structure, and built a timber frame passive house inside the historic masonry farm structure (Welch et al., 2023). This mirrors the common practice from the United States as a simple way to create a means of adding insulation.

The Victorian Terrace house, on the other hand, preserved the interior details by using Aerogel. As a product, Aerogel has produced favorable results within the historic retrofit community for its efficiency at small thicknesses, allowing retention of details that would have otherwise been swallowed up by insulation. The Victorian House included more traditional methods, such as mineral wool and polyisocyanurate (PIR) insulation and triple pane windows, but it also introduced and explored a variety of newer and more advanced techniques for its building envelope, like vacuum windows and vacuum insulation as well as silica-Aerogel, starch-Aerogel insulation and gypsum air infiltration for air sealing (Welch et al., 2023). Classed as a Super Insulation, Aerogel has the highest insulation value of any known material with the lowest thermal conductivity value of any solid (0.015W/mK). Available in easy to use solutions for applications in all sectors including building and construction, refurbishments and energy efficiency retrofits. The thinnest and easiest solution to insulate hard to treat areas, especially where space is at a premium and where critical tolerances have to be achieved (High Performance Thermal Insulation - Thermablok Aerogel, n.d.). A single 10mm thickness of Thermablok Aerogel Insulation Blanket increases the insulation factor of a standard solid wall construction by up to 67% (High Performance Thermal Insulation - Thermablok Aerogel, n.d.). However, aerogel is very expensive, so it is best used sparingly, like when preserving significant details (Welch et al., 2023). Although Aerogel is very effective, its cost and limited availability poses issues for its use on a larger scale.

Stratton Hall, Worcester, MA

Original

Retrofitting a mass masonry structure is a crucial step in enhancing energy efficiency, comfort, and sustainability. Several best practices have been identified and these practices are essential for optimizing the performance of such buildings. To begin with, the original building was a mass masonry structure with dimensions of 35m x 16m x 17m totaling 9520 cubic meters and a WWR of about 25% with no insulation in the walls or roof. The wall makeup was a mass masonry brick wall on a sandstone base and a thin interior finish board (Thomas, 2012). In a meeting with Nick Palumbo, a director of design and construction for the Stratton hall renovation, he discussed that the roof is a simple makeup of wooden plank decking felt and tar that all sits on top of the steel framing. The original windows were wooden framed single glazed windows, but there was a renovation in 2011 that upgraded the windows to aluminum framed double glazed windows. This became the start point for the retrofit of the envelope of the building.

As an older building, Stratton Hall has had air leakage issues inherent to the constructions used. Using an average of 0.7 ac/h air exchange rate, we assumed that the original building had a slightly worse air exchange rate at .725 ac/h to account for the worse air leakage (*Greenhouse Gas Reduction Plan*, 2017). The original HVAC is a radiator and boiler system which is overall inefficient and does not allow for local control which in a large area building such as this one can improve on energy efficiency (*Greenhouse Gas Reduction Plan*, 2017). As for lighting, the original lighting system used inefficient lights that were all manually controlled. This means that not only were the lights less energy-efficient when they were actually in use, they would be left on when parts of the building were not in use. This is due to it being an open academic building on campus at all hours making for a costly drop in overall energy efficiency (*Greenhouse Gas Reduction Plan*, 2017). Unneeded energy usage such as this was costly to the overall energy efficiency of the building.

In 2017, a study on WPI campus was conducted to investigate energy efficiency of buildings. GreenerU, a firm with substantial experience in campus energy efficiency auditing and upgrades was engaged to continue previous work in auditing campus buildings for energy usage and efficiency upgrade potential (*Greenhouse Gas Reduction Plan*, 2017). In this study, Stratton Hall was audited and as a result, Stratton Hall was found to have a Net Source EUI of 344 kWh/m^2/yr (*Greenhouse Gas Reduction Plan*, 2017). This is the calculation of the actual energy usage of the building as a whole including any energy production off site in order to supply the building. This value was then used to find Net Site EUI to be 134 kWh/m^2/yr which is the energy usage of the building itself on site which includes heating, cooling, electricity, water, and anything else that requires energy usage to operate. From this value and an extensive background of the construction of the building, we were able to model Stratton Hall in Worcester's climate using Design Builder within an 8% accuracy. With a model close enough in EUI to depict the actual building, we backtracked the construction materials to match the makeup of the building when it was originally built in 1894. The resulting Net Site EUI was 183 kWh/m^2/yr. This became our starting point for our retrofitting design process.

Code Compliance

Our first benchmark for retrofitting Stratton Hall was investigating the resulting Net Site EUI of bringing the building up to code compliance. The only focus for this benchmark was improving the insulation and U-Values of the walls, windows, and roof. In the section “Code Framework” of this paper, the maximum U-Values for all of these sections are shown and were the values used to bring the building to the minimum code requirements. The wall, from exterior to interior, was upgraded to have brick, rigid extruded polystyrene insulation, metal stud cavity filled with fiberglass batt insulation, an AVB membrane, and a gypsum board finish to accomplish the required U-Value of U-0.088 continuous insulation. This was the next step in the progression of the building envelope.

The roof utilized a similar strategy starting from a new exterior roof membrane, we added a layer of plywood, rigid polystyrene insulation, another roof membrane layer, wooden plank decking, batt insulation in the joist cavities, and interior sheathing to accomplish the required U-Value of U-0.020 continuous insulation. Lastly, the windows were upgraded from the starting single glazed windows to double glazed, aluminum framed windows to meet the required U-Value and air leakage rate.

We chose to design the retrofit this way because it was the most efficient while also being least invasive to the original structure. These improvements achieved minimum code compliance requirements resulting in reaching our first milestone in our retrofit renovation design.

Deep Energy Retrofit

Deep Energy Retrofit is a benchmark standard that requires the retrofitting design to reduce the building EUI by 50% in order to achieve DER accreditation. In order to reach this benchmark, we improved the insulation of the walls, windows, and roof as well as improving air leakage rate, lighting efficiency, and HVAC efficiency. For the wall and roof insulation, a higher performing rigid insulation material was selected, known as polyisocyanurate rigid insulation, to decrease the overall U-Value of both sections without increasing the thickness. The windows were further improved by upgrading them to aluminum framed, double glazed, low-e, argon filled windows. This means that the windows have become more thermally efficient, letting in less heat in the summer and keeping in more heat in the winter. The air leakage rate was improved beyond the standard 0.7 ac/h to 0.65 ac/h, under the assumption that when the windows are being replaced and upgraded, the window to wall connection will be resealed and the envelope will be retrofit to a high quality resulting in less air leakage in the building as a whole.

As discussed before, the current lighting and HVAC systems are inefficient and could be majorly improved to reduce energy usage. Smart LED lighting was used in the model to improve the electrical efficiency. This means that not only are the bulbs themselves more efficient than before, but when rooms or sections of the building are not in active use, the lights will shut off automatically by using motion sensors. This makes a huge difference in energy conservation for the building because it is not wasting electrical energy when it does not need to. For the HVAC system, the current radiator and boiler system is inefficient and out-dated for the building. Therefore, in the energy model we upgraded to a Variable Air Volume system. The VAV system can meet heating, cooling, and airflow requirements on a zone by zone basis. Unlike most other air distribution systems, VAV systems use flow control to efficiently condition each building zone while maintaining required minimum flow rates meaning it can condition specific zones independently from others, saving energy by not having to heat or cool the entire building. With these strategies we reached our next milestone of becoming a DER Certified building by reducing the EUI by at least 50%.

Net Zero

Net Zero building design is the practice of having energy production on the site through RES so that the resulting Net Site EUI falls below zero. The most common strategy for achieving this benchmark is the use of solar panels but first it is important to lower the energy usage by the building as much as possible. This process involved ensuring the insulation in the walls, roof, floor, and windows were continuous and a low enough U-Value while not impeding on interior space. Shading devices were optimized to allow heat light and heat into the building in the winter and less in the summer. Also, the efficiency of the new systems that were emplaced for heating, cooling, lighting, and water were improved to 95%. These additional changes greatly reduced the EUI of the building. This was the largest reduction achieved without the use of solar panels. With the availability of a flat roof, it is fairly simple to incorporate solar panels. After adding solar panels on the roof while leaving space for maintenance and access, the solar panel production potential, combined with all the other previous strategies, brought the Net Site EUI down to achieve Net Zero (NREL, 2019). This result means that the final goal has been achieved and Stratton Hall is now producing more energy than it is consuming. Included below in this section are the final schematic detail section drawings of the Stratton Hall retrofit.

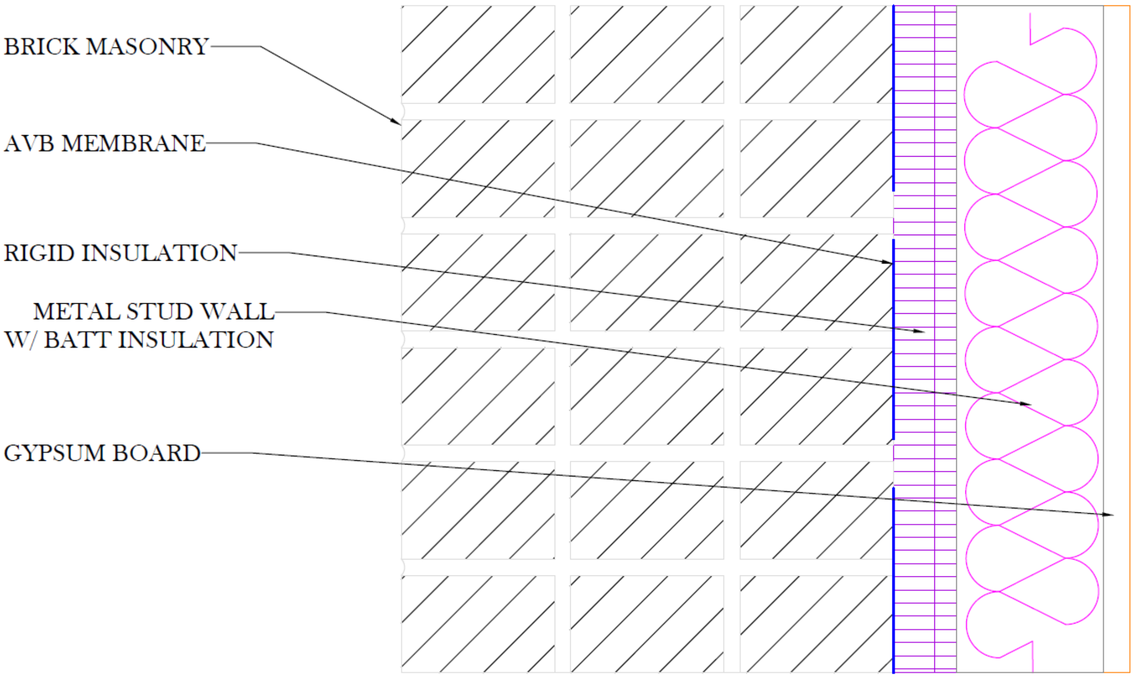


Figure 8: Stratton Hall Schematic Drawing 1-Wall Section

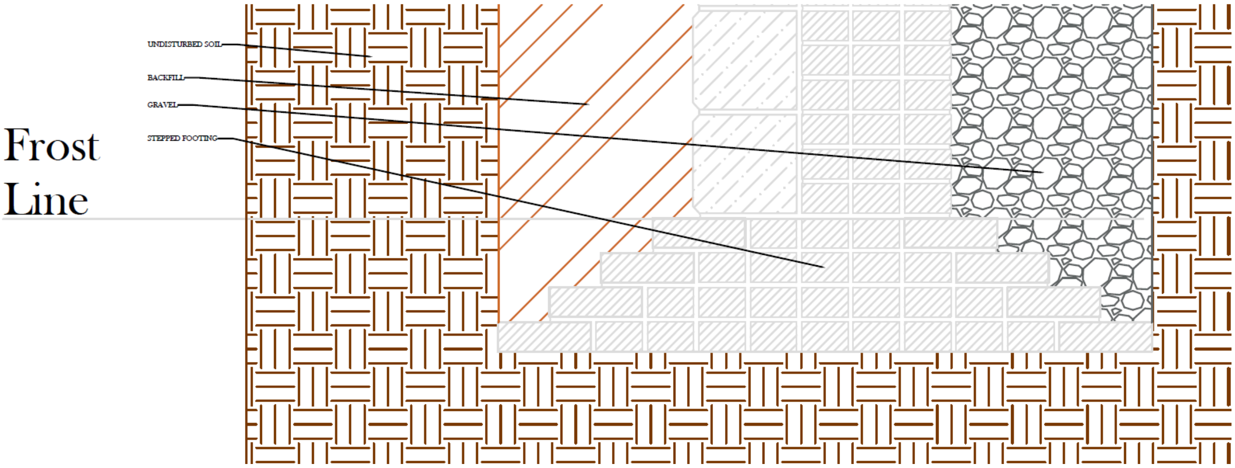


Figure 9: Stratton Hall Schematic Drawing 2-Wall to Foundation Section

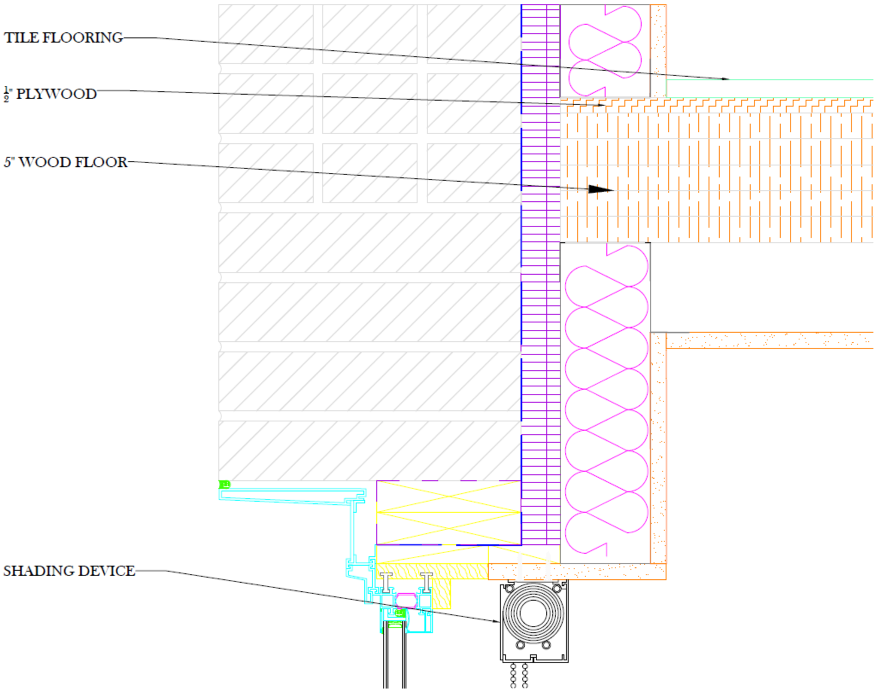


Figure 10: Stratton Hall Schematic Drawing 3-Upper Window Section

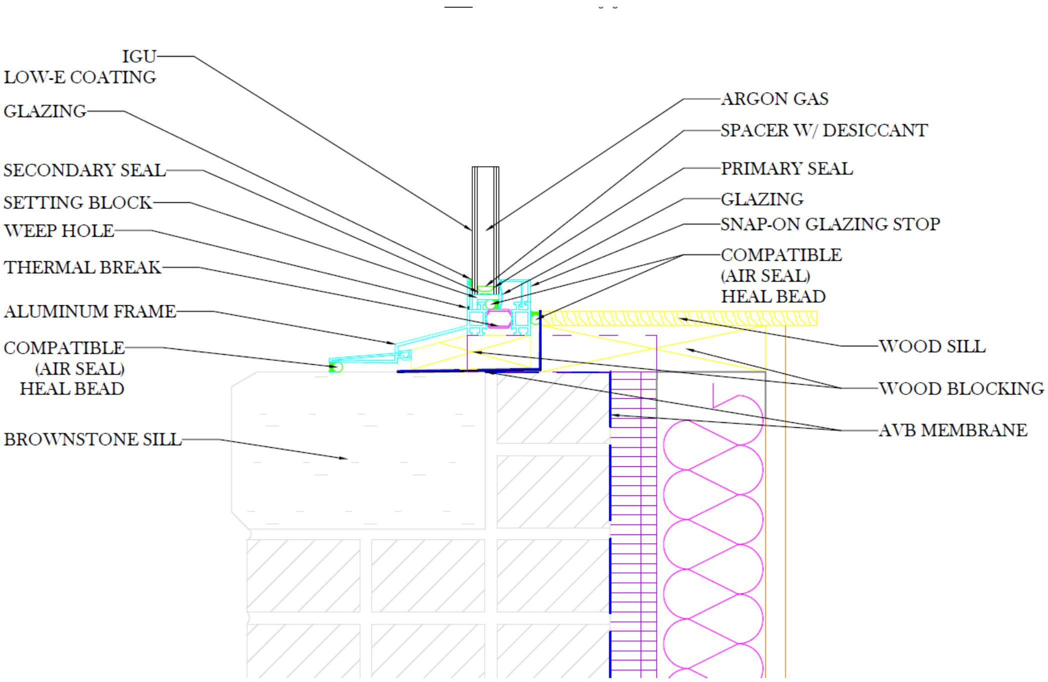


Figure 11: Stratton Hall Schematic Drawing 4-Lower Window Section

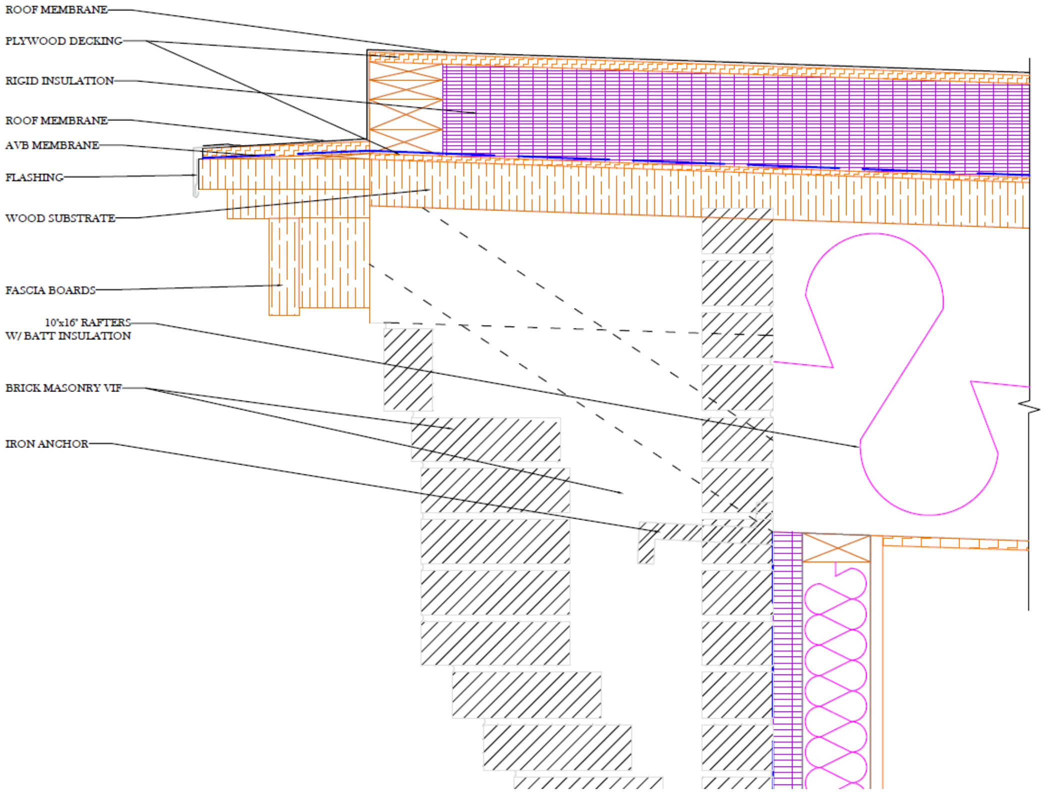


Figure 12: Stratton Hall Schematic Drawing 5-Wall to Roof Section

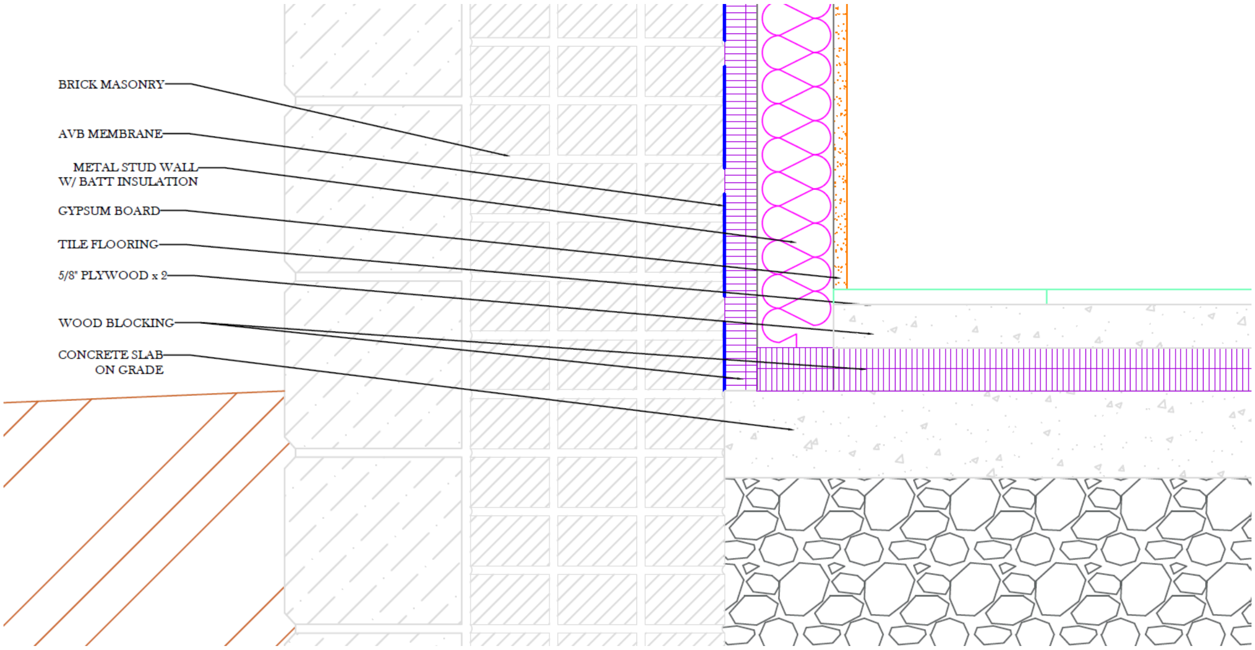


Figure 13: Stratton Hall Schematic Drawing 6-Wall to Slab on Grade Section

Building 12, Lecco, IT

Original

The original construction of Building 12 on the Lecco campus of Politecnico di Milano is very similar to that of Stratton Hall in Worcester. It too, was originally built using mass masonry walls and slab on grade containing little to no insulation in both. The building is made up of three different facade levels: the first floor is limestone, the second floor is brick, and the third and fourth floor are stucco plaster. The interior finish was a thin plaster board. Building 12 is a larger scale, and less geometric shape than Stratton Hall making it harder to work with, but it does still have a similar WWR of about 20%. The original windows were aluminum framed single glazed windows, but there was a renovation that upgraded the windows to aluminum framed double glazed windows. The largest difference between the two buildings is the roof. The Building 12 roof is a pitched clay tile roof that sits on wood rafters.

As an older building and as part of our comparison, Building 12 was given the same starting parameters as Stratton Hall. Using an average of 0.7 ac/h air exchange rate, we assumed that the original building had a slightly worse air exchange rate at .725 ac/h to account for the worse air leakage. The original HVAC is a radiator and boiler system which is overall inefficient and does not allow a lot of local control which a large area this building can improve on energy efficiency. As for lighting, the original lighting system used inefficient lights that were all manually controlled. This means that not only were the lights less energy-efficient when they were actually in use, they would be left on when parts of the building were not in use. This is due to it being an open academic building on campus making for a costly drop in overall energy efficiency.

This gave us base conditions to be able to compare the two different building case studies to see what changes work better for the differing areas. This included backtracking once again to match the state of the building when it was originally built with single glazed windows. With all these original conditions set, Building 12 had an EUI of 149 kWh/m²/yr. This became our starting point for our retrofitting design.

Code Compliance

Utilizing the strategies investigated in the Milan hotel case study we retrofitted the envelope of Building 12 to reach Italian code compliance. This was accomplished by replacing the existing windows with better performing double glazed, low-e, and argon filled windows with exterior operable shading devices. On the interior, a floor to ceiling metal stud system that is also filled with rockwool batt insulation was added against the brick masonry. The metal stud system is then encased by a layer of gypsum board. The same rockwool insulation was used to insulate the rafters in the roof and was sheathed in as well as a layer of rigid xps insulation added to the floor system. This was only to meet the minimum code requirements to give a sense of the impact it would have on the EUI, but this left much to further improve.

Deep Energy Retrofit

With a base concept of how to improve the insulation and systems when retrofitting, we continued to improve our design to reach a status of DER. This began with a further improvement of insulation in all areas. First the walls were insulated on the interior by a metal stud system filled with rockwool insulation separated from the masonry wall by an air gap. The metal stud system was then sheathed by a double layer of gypsum board with a foil faced vapor barrier in between. As for the windows, they were upgraded to double glazed, low-e, argon filled, aluminum framed windows with added insulation in the sills to avoid more thermal bridging. The described windows are depicted in Building 12 Schematic Drawings 2 and 3 and are standard practice in Italy. The roof rafters are filled with the rock wool insulation and sheathed with cross laminated structural panels. The foundation and slab system is a cupolex system to allow for mechanical systems that is topped with concrete and a joist system filled with more rice husk insulation. The exterior foundation footing is also wrapped in a layer of xps rigid insulation to reduce thermal bridging. This covers the entirety of insulating the envelope of the building.

With the envelope done it did not take much to reduce the EUI below 50% to reach DER. All that was necessary was the substitution of the original boiler with a condensing gas boiler (theoretical efficiency equal to 0.95). The existing chiller is used as a cooling system in this retrofit design just as described in the Milan hotel case study. This combined with reducing the ac/h past the average building ac/h of 0.7 to 0.6, because it is newer than Stratton Hall and a newly retrofitted building, achieved the next step of a DER.

Net Zero

With such a large reduction as a result of the envelope and boiler change to achieve DER, this left little to do to reduce the EUI before being able to add solar panels to reach Net Zero. The envelope was complete with insulation and the boiler replaced, but left was the efficiency of the water and lighting systems. The modeled lights were upgraded to smart LED lights that followed the occupancy of the typical classroom and office zones of the building while both systems efficiency was upgraded to 95% ultimately bringing the EUI down to its lowest without solar panels. This significant reduction allowed for the addition of solar panels to reach the goal of a Net Zero building. Since the roof is slanted rather than flat, the solar panels were more difficult to add and orient therefore the overall photovoltaic potential was lower than that of Stratton Hall, but still allowed the goal of Net Zero to be met (NREL, 2019). This completes the retrofit of both buildings by reaching modeled Net Zero status. Figures 14 through 18 are the schematic drawings of the section details of the envelope for Building 12.

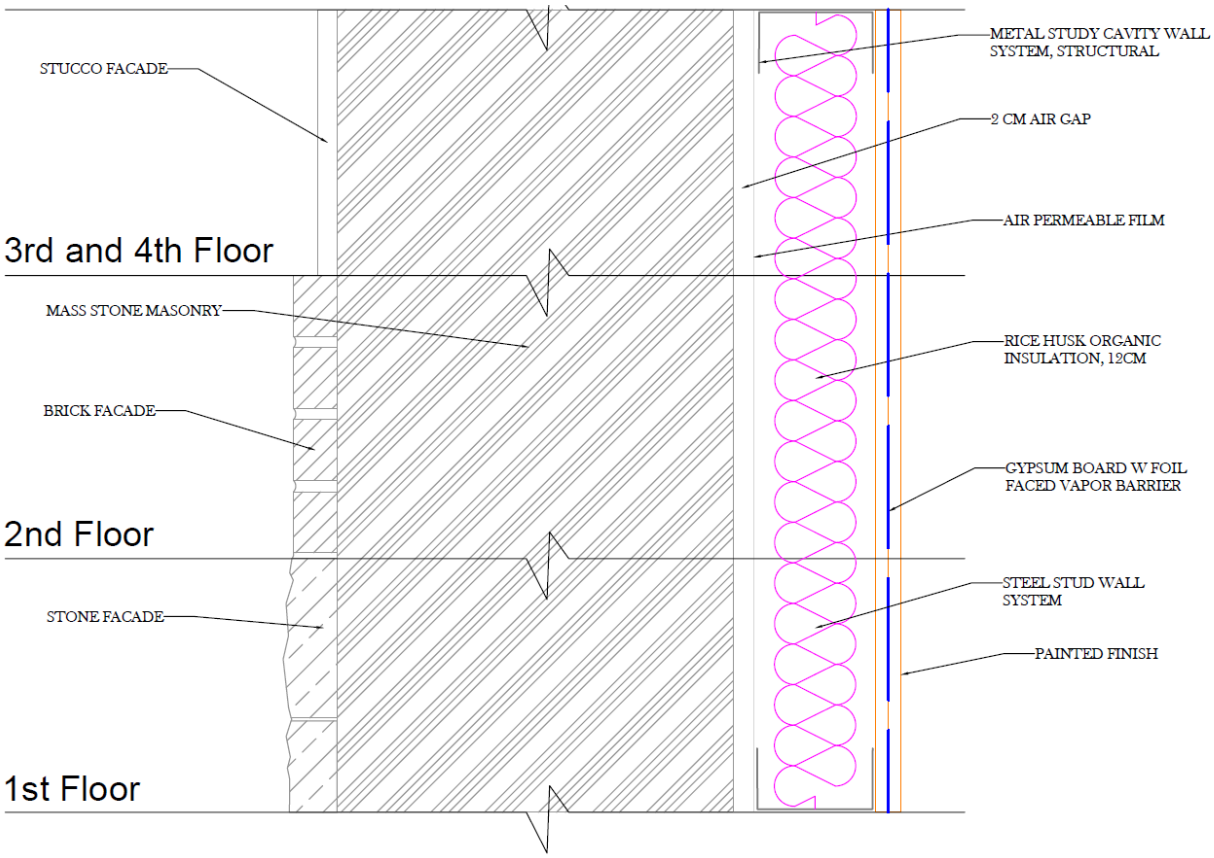


Figure 14: Building 12 Schematic Drawing 1-Wall Section

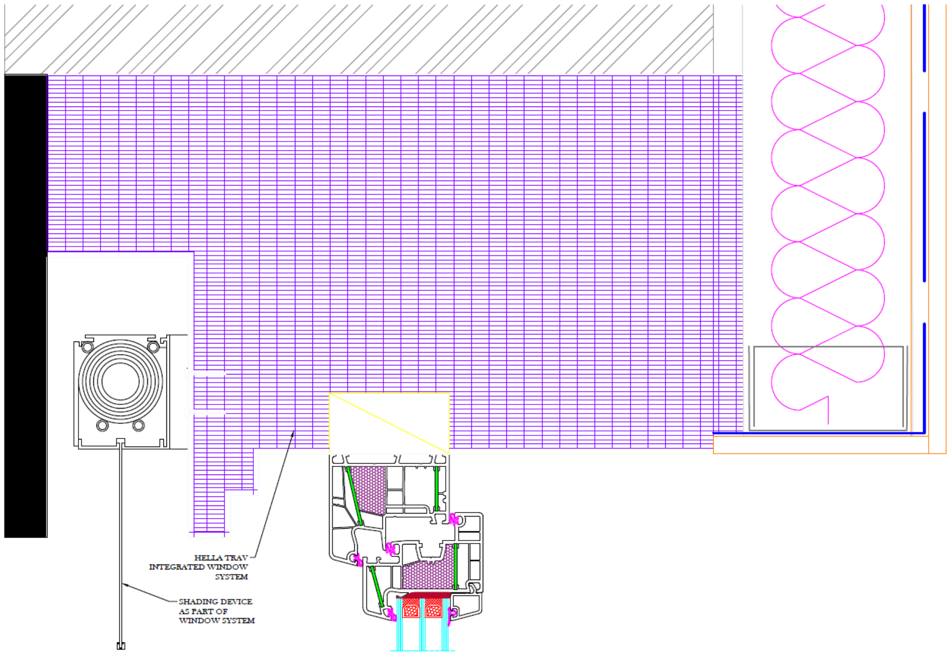


Figure 15: Building 12 Schematic Drawing 2-Upper Window Section

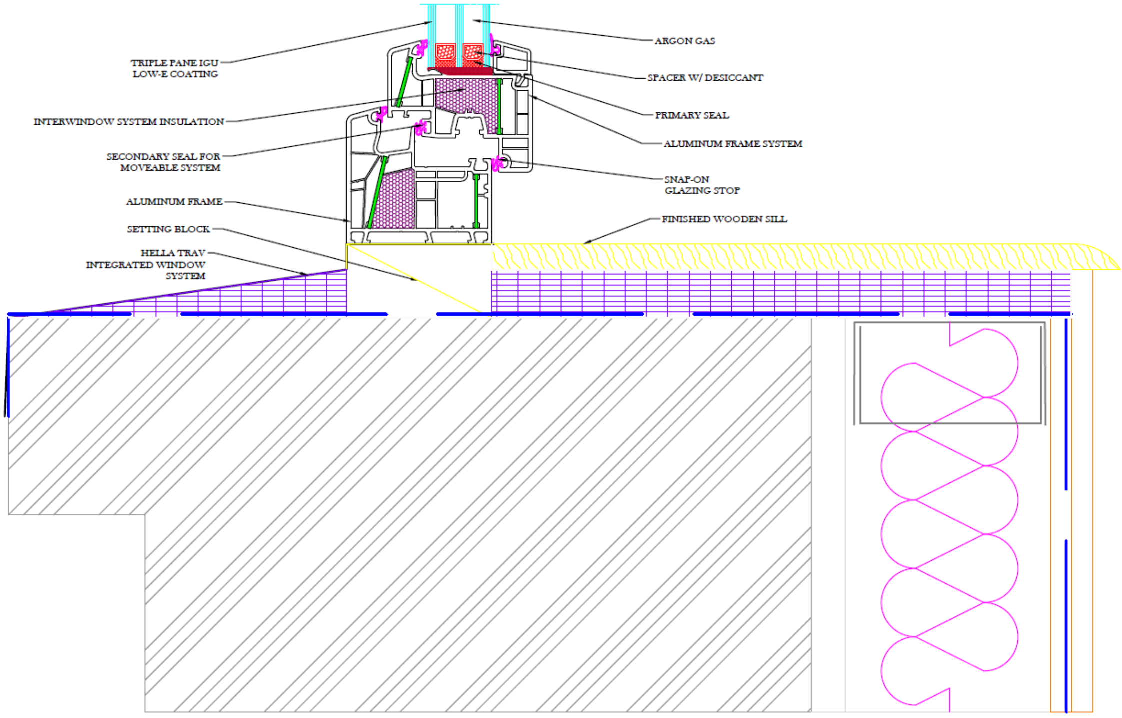


Figure 16: Building 12 Schematic Drawing 3-Lower Window Section

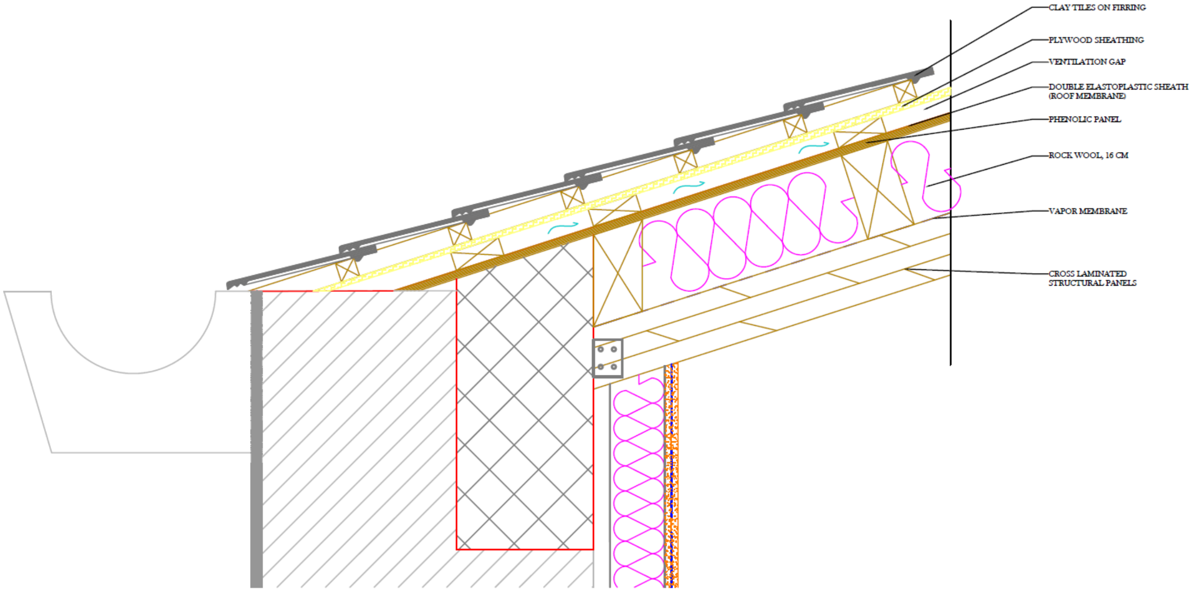


Figure 17: Building 12 Schematic Drawing 4-Wall to Roof Section

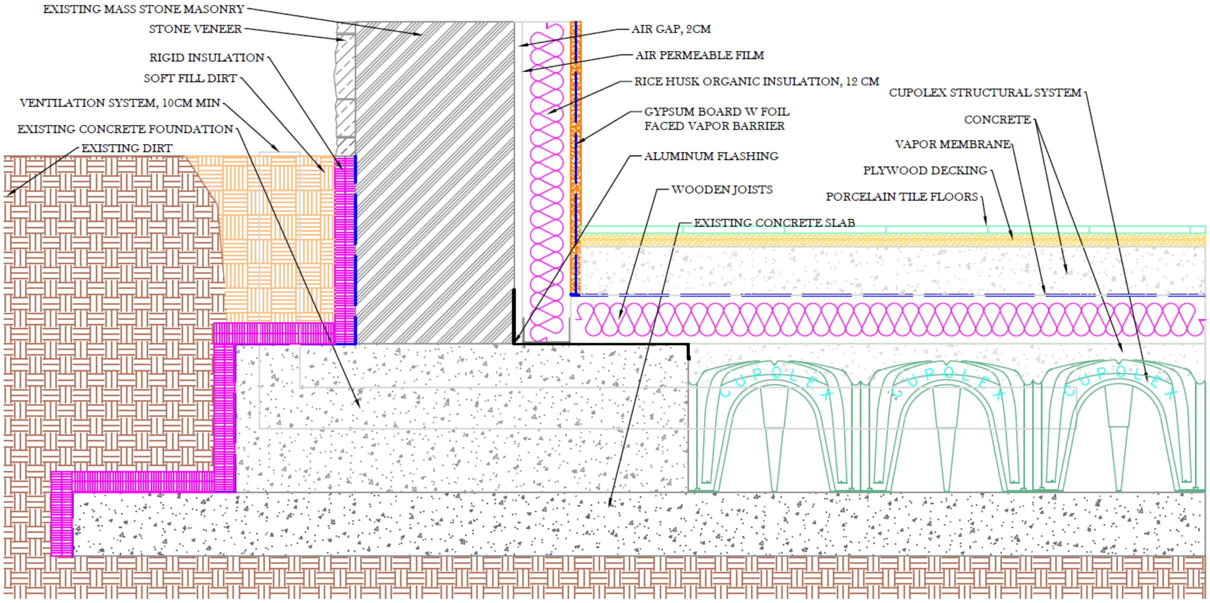


Figure 18: Building 12 Schematic Drawing 5-Wall to Foundation Section

Results

Stratton Hall

Code Compliance Analysis

Energy code compliance for the Stratton Hall retrofit was continuously a trade-off between perfect and practical design. In the US, energy codes have evolved into a regulation subsidized by a financial backing to allow for the promotion of more energy-efficient buildings. This evolution has allowed for an uptick in the creation of new energy-efficient buildings and renovations focused on not only the aesthetic of a building renovation, but also the energy efficiency upgrades possible.

The IECC 2021 was the guidebook for our design and starting with the building envelope we were able to create a design that not only was justified practically but also through code. Each opaque building element designed in the retrofit was able to meet minimum energy code requirements, confirmed through the heat transfer analysis done with THERM.

Additionally, our designs were able to meet the compliance in other areas of an energy-efficient building. Our WWR was 25:100 which is below the threshold similar to the original building and we did not add any additional windows. Another energy code requirement we were able to meet was the maximum air leakage rate for fenestrations. This required that all types of doors and windows were below the maximum set for each fenestration assembly which we were able to input within the Design Builder software.

Moving onto heating and cooling within our building we used a selection system as discussed within the background code compliance section which enabled us to select an HVAC system that is ASHRAE approved and Energy Star Certified. We selected different systems coupled with efficiencies based on those certifications to determine which system allowed us to have the lowest EUI.

Looking at the energy code for lighting systems we followed a similar process as we did for the HVAC system. When retrofitting a building such as Stratton Hall we decided to implement luminaries in the design builder simulation with an efficacy of 40 lm/W in 100% of the permanently installed lighting systems which exceeds the energy code. Additionally, we added daylight controls on all spaces within the building that received limited daylight.

Finally, when analyzing the EUI we looked to ASHRAE Standard 100 - 1018 to set a target for existing college/university buildings in climate zone 5A to be below 246 kWh/m^2/yr. This target will be discussed further in the following section on EUI breakdown.

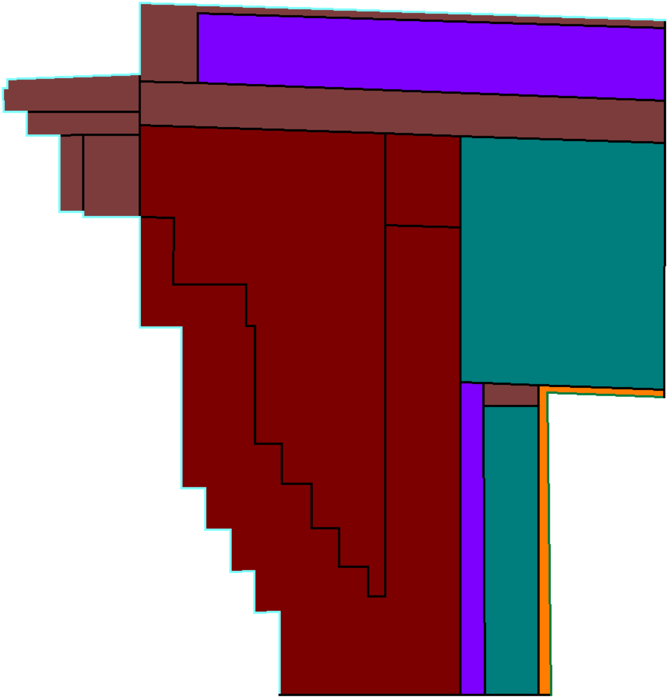
Heat Transfer Analysis

Once the initial iterations of the details shown previously were complete we began to analyze the heat transfer of the elements examined. Using THERM allowed us to model all the critical details that may lead to thermal bridging or poor thermal performance in a building. We were able to analyze the risk of thermal bridging and determine an accurate U-Value for the envelope components needed to pass energy code requirements found in Table 2. Using the data shown in Table 10 or Table 11 in Appendix B we accurately input the correct thermal conductivity and emissivity to the material used in our design. This allowed us to create a strong picture of the assembly.

Table 10: Simplified THERM Material Key

Material	Color	Thermal Conductivity ($W/(m^2 \cdot {}^\circ C)$)	Source	Material	Color	Thermal Conductivity ($W/(m^2 \cdot {}^\circ C)$)	Source
Softwood	🟧	0.11	THERM	Granite	⬛	2.99	OSTI.GOV
Fiberglass (PE Resin)	🟦	0.3	THERM	Soft Dirt	🟫	1.1	OSTI.GOV
Gypsum Board	🟧	0.2	THERM	Dirt	🟫	1	OSTI.GOV
Brick	🟥	0.75	THERM	Concrete	⬜	0.2	OSTI.GOV
Hardwoods	🟫	0.16	THERM	Gravel	🟩	1.2	OSTI.GOV
XPS Insulation	🟪	0.029	THERM	Air, Moving	🟦	24	THERM
Air	🟦	1.01	THERM	Clay Tiles	🟫	0.7	OSTI.GOV
Aluminum Frame	🟦	237	THERM	Phenolic Panel	🟨	0.018	OSTI.GOV
Silicone	🟪	0.35	THERM	Rockwool Insulation	🟩	0.035	THERM
Steel	⬜	45	THERM	Plaster	🟫	0.5	THERM
Urethene	🟨	0.12	THERM	XPS w CFC and HCFC	🟫	0.03	THERM
Glass	🟦	1	THERM	Tile Flooring	🟦	10	OSTI.GOV
Air, Argon	🟪	0.09	THERM	Wood Flooring	🟨	0.14	THERM
Structural Panels	🟥	0.1	THERM	Silicone Foam	🟪	0.17	THERM

Beginning with the wall to roof and wall to foundation details we looked to analyze the heat transfer through important connections in our design. We looked for thermal bridging, temperature patterns and to determine any energy inefficiencies in the assembly.



Material	Color
Brick	🟥
Fiberglass (PE Resin)	🟦
Gypsum Board	🟧
Hardwoods	🟫
XPS Insulation	🟪

Figure 19: Stratton Wall to Roof THERM Component Blocks

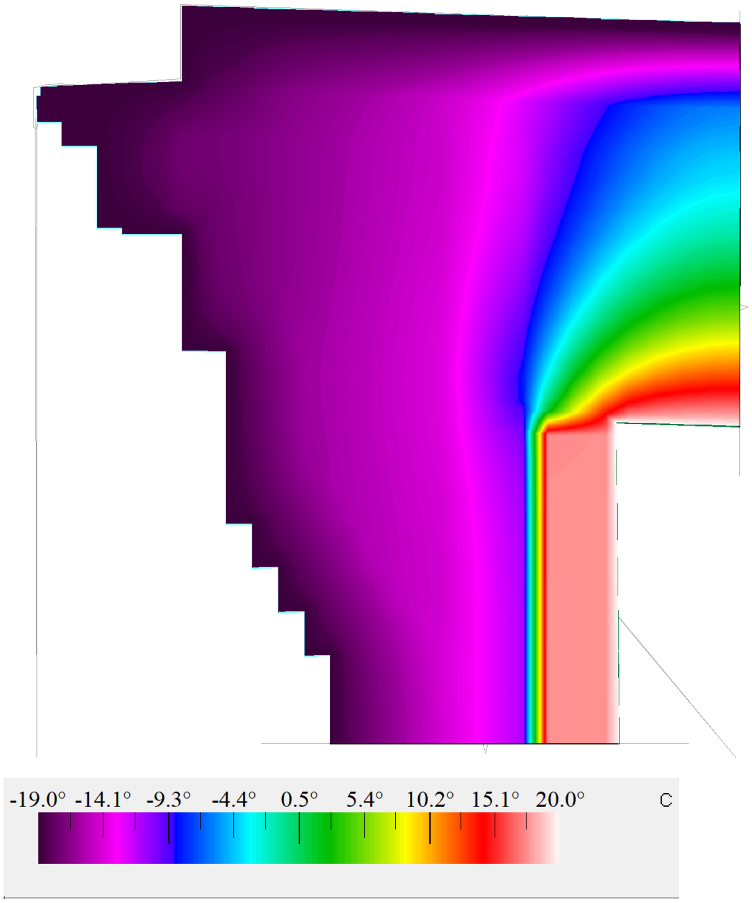
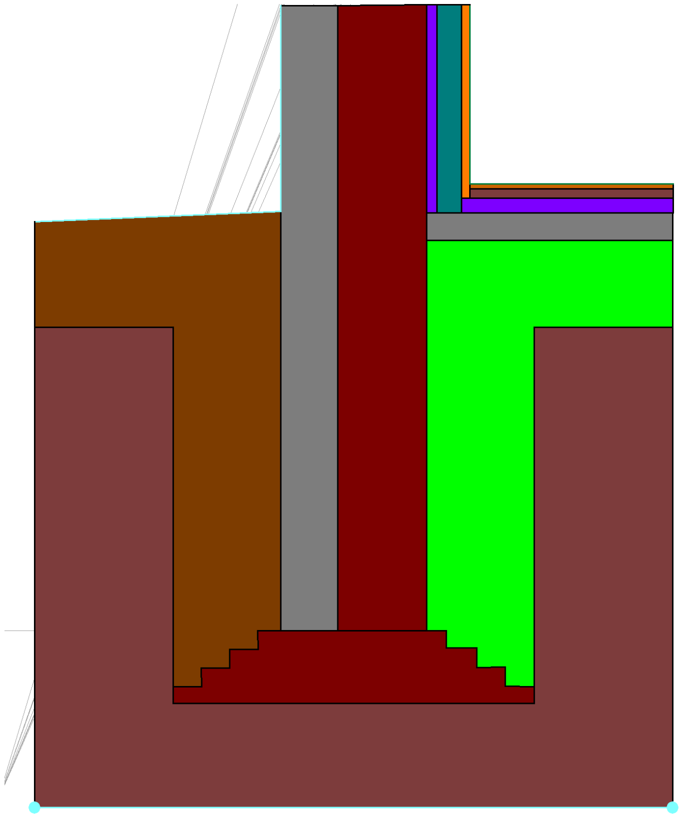


Figure 20: Stratton Wall to Roof THERM Thermal Gradient

Based on Figures 19 & 20 we can determine that the wall to roof temperature pattern is sufficient for a modern building. There is no clear thermal bridging and the insulation acts as a barrier to the outdoor conditions.



Material	Color
Brick	🟥
Fiberglass (PE Resin)	🟦
Gypsum Board	🟧
Hardwoods	🟫
XPS Insulation	🟪
Granite	⬛
Concrete	⬜
Gravel	🟩
Soft Dirt	🟫
Dirt	🟫
Wood Flooring	🟨

Figure 21: Stratton Wall to Foundation THERM Component Blocks

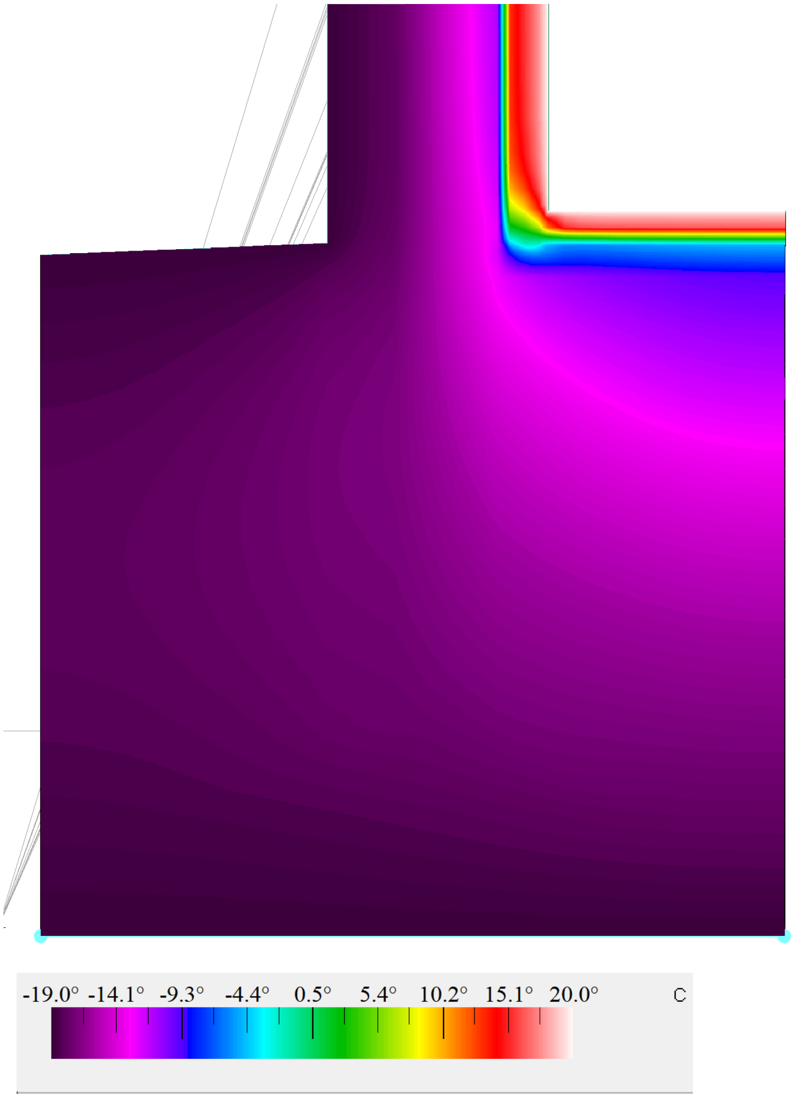
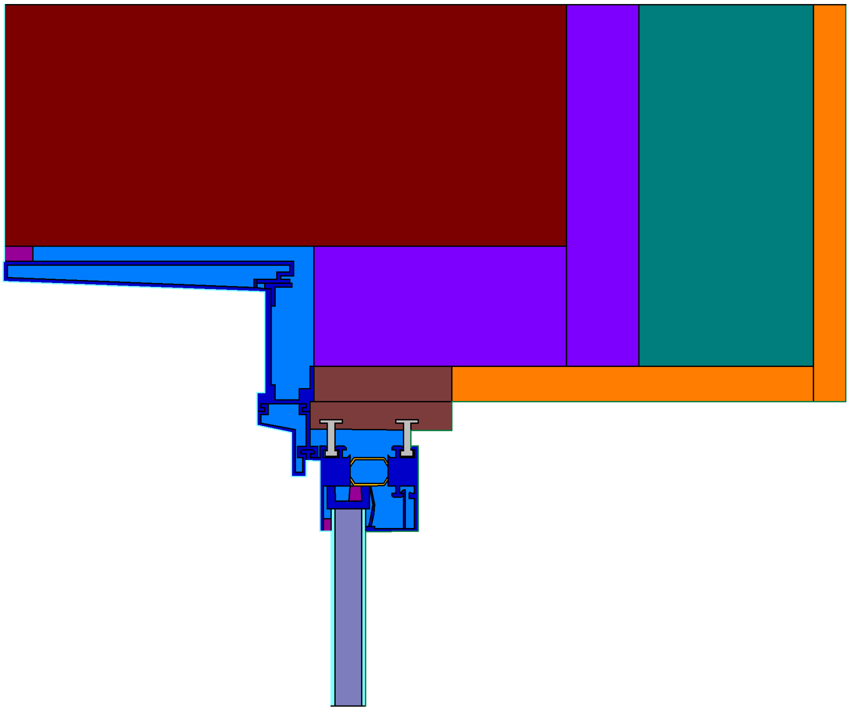


Figure 22: Stratton Wall to Foundation THERM Thermal Gradient

Based on Figure 21 & 22 we can determine that the wall to foundation is sufficient in its ability to prevent heat transfer from the outside to the inside.

Once we looked at the connections for the building we used the software to examine both the window sill and head to confirm the manufacturer's stated U-Value and look for thermal bridging in the assembly.



Material	Color
Brick	🟥
Fiberglass (PE Resin)	🟩
Gypsum Board	🟧
Hardwoods	🟫
XPS Insulation	🟪
Air	🟦
Aluminum Frame	🟦
Silicone	🟪
Steel	⬜
Urethene	🟨
Glass	🟦
Air, Argon	🟪

Figure 23: Stratton Window Head THERM Component Blocks

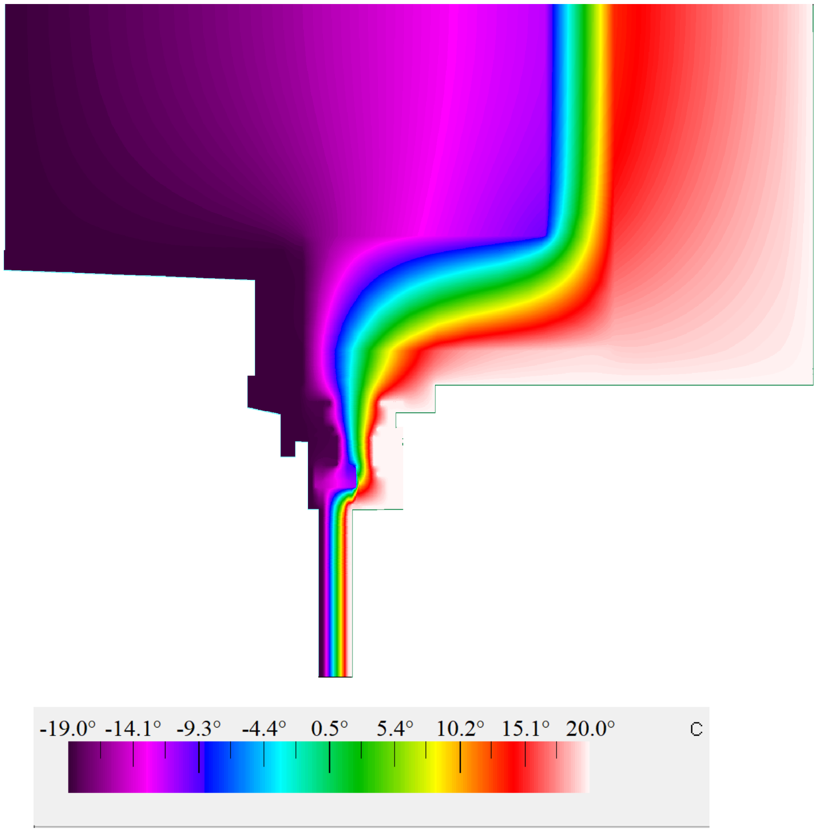
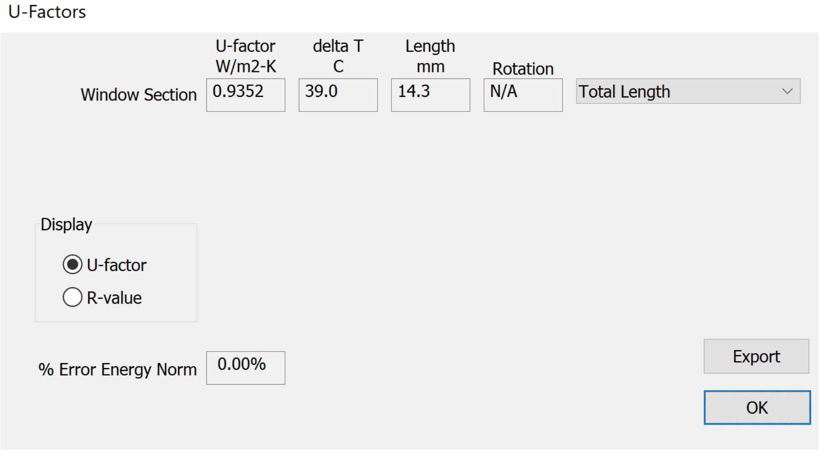


Figure 24: Stratton Window Head THERM Thermal Gradient



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Window Section	0.9352	39.0	14.3	N/A	Total Length

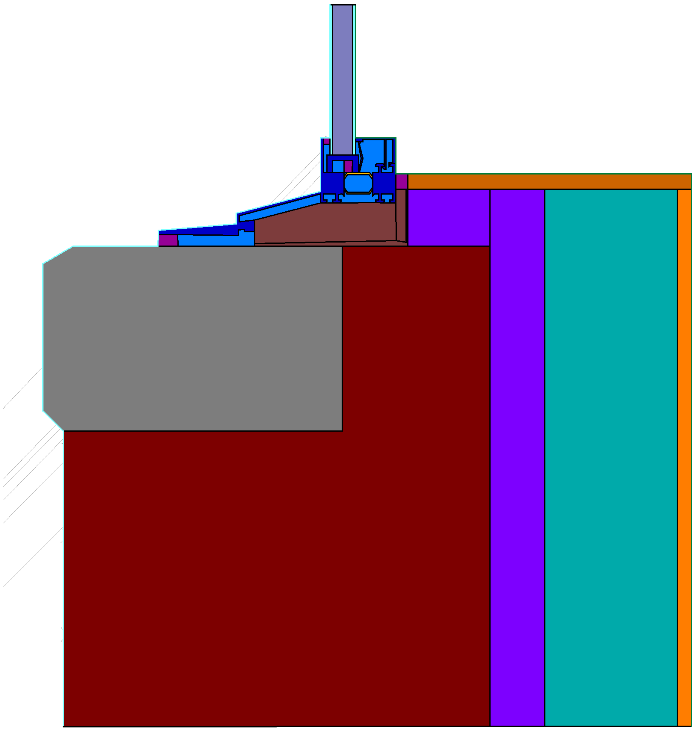
Display

● U-factor
○ R-value

% Error Energy Norm 0.00%

Figure 25: Stratton Window Head THERM Calculated U-Value

Based on Figures 23, 24, and 25 we can determine that there are no thermal gradients that exist within the window system at the head and that our calculated U-Value meets code. The U-Value we calculated differs from the manufacturer tested U-Value of 0.95 simply because our calculation does not perfectly align with the manufacturer’s thermal conductivity values. This however confirms that our window system is below the maximum value of 3.975 (W/(m²·°C)) found in the *Building Envelope* section.



Material	Color
Brick	🟥
Fiberglass (PE Resin)	🟩
Gypsum Board	🟧
Hardwoods	🟫
XPS Insulation	🟪
Air	🟦
Aluminum Frame	🟦
Silicone	🟪
Steel	⬜
Urethene	🟨
Glass	🟦
Air, Argon	🟪

Figure 26: Stratton Window Sill THERM Component Blocks

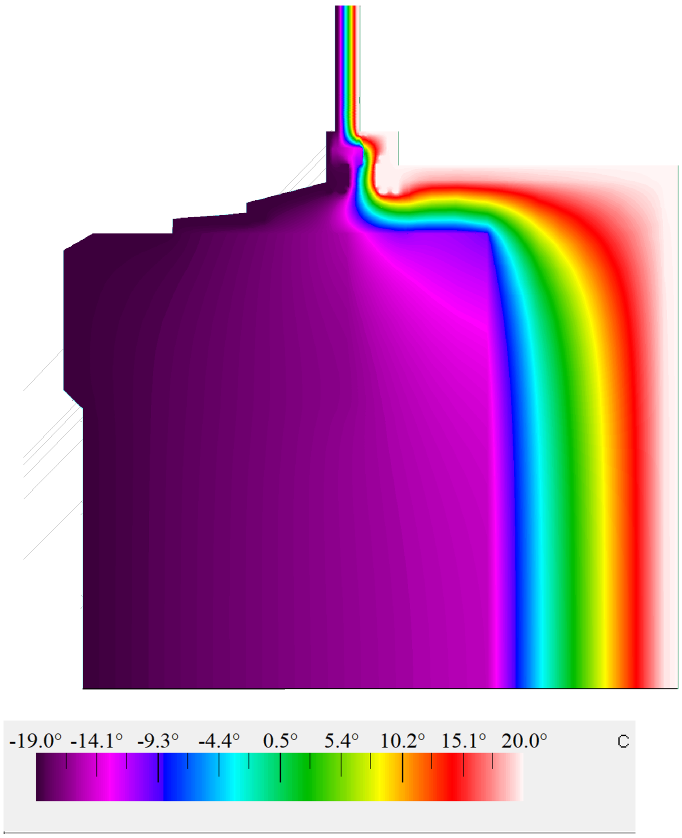
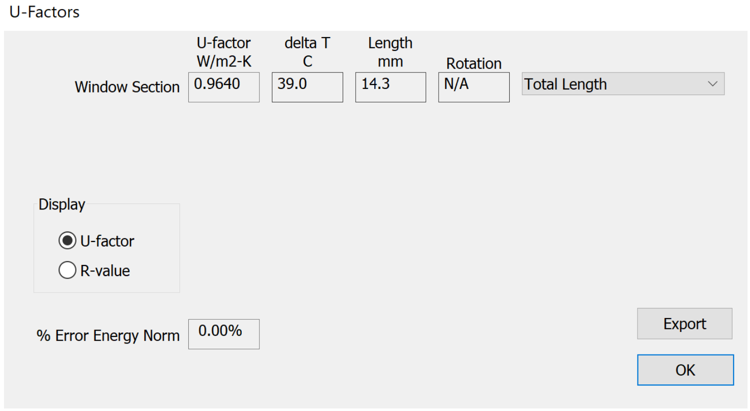


Figure 27: Stratton Window Sill THERM Thermal Gradient



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Window Section	0.9640	39.0	14.3	N/A	Total Length

Display

● U-factor
○ R-value

% Error Energy Norm 0.00%

Figure 28: Stratton Window Sill THERM Calculated U-Value

Based on Figure 26, 27, and 28 we can determine that the window sill for our Stratton Hall design is up to code as stated in conjunction with the window head analysis done previously. Similarly to the window head we have small differences in the THERM that cause the change in U-factor calculation.

Finally to confirm that our retrofit design met US energy code compliance we used the software to determine the U-Value of the roof, wall and floor assemblies. The heat analysis done on these elements is shown below with the corresponding software calculated U-Value.

Material	Color
Fiberglass (PE Resin)	🟦
Gypsum Board	🟧
Hardwoods	🟫
XPS Insulation	🟪

Figure 29: Stratton Roof THERM Component Blocks

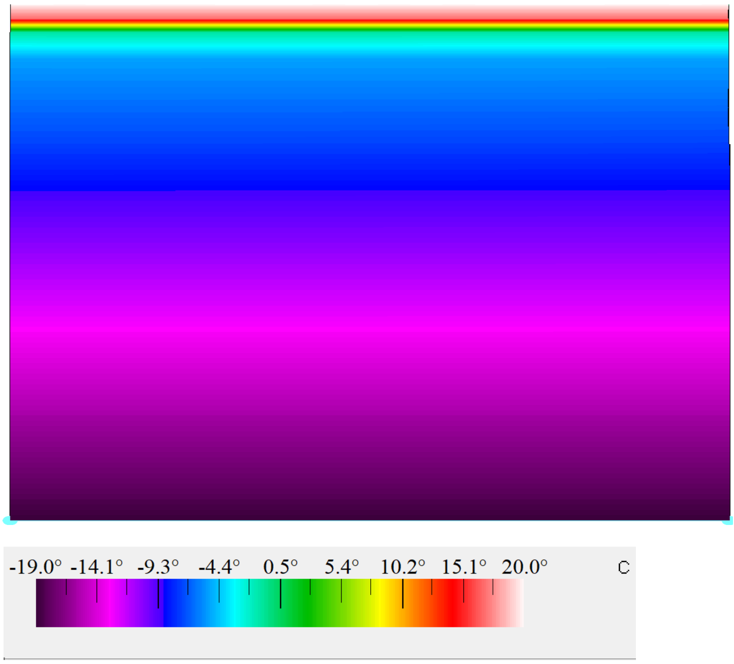
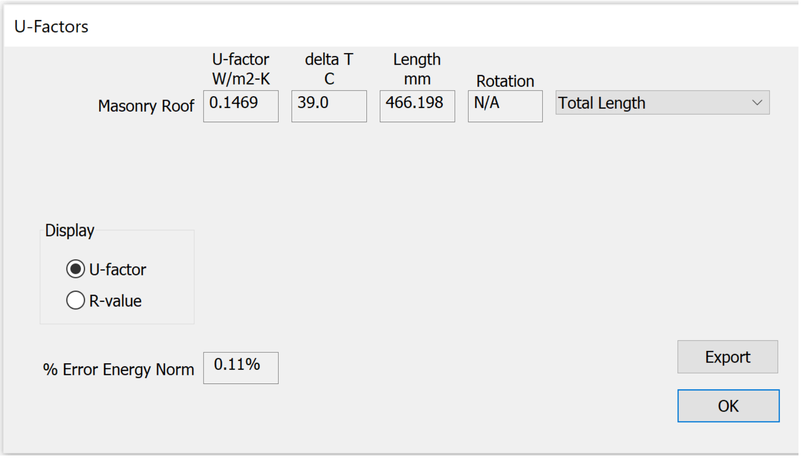


Figure 30: Stratton Roof THERM Thermal Gradient



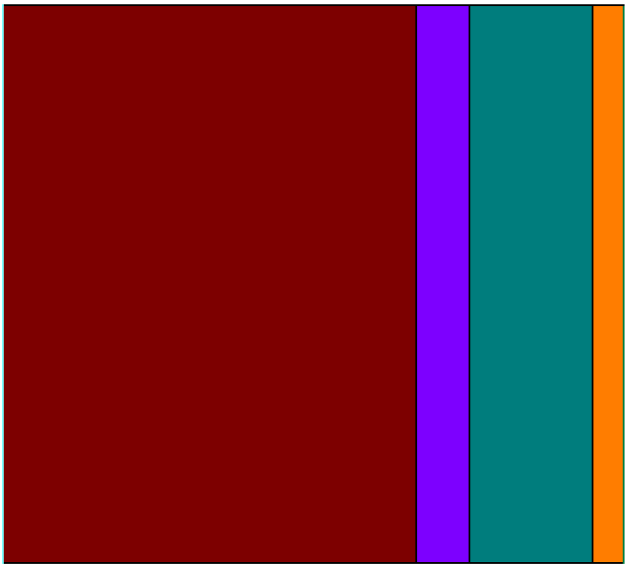
	U-factor W/m2-K	delta T C	Length mm	Rotation	
Masonry Roof	0.1469	39.0	466.198	N/A	Total Length

Display
● U-factor
○ R-value

% Error Energy Norm 0.11%

Figure 31: Stratton Roof THERM Calculated U-Value

Based on Figure 29, 30, and 31 we can determine that when taking a section cut of the roof the calculated U-Value meets the energy code requirements of 0.18 (W/(m²·°C)) for our specified building.



Material	Color
Brick	🟥
Fiberglass (PE Resin)	🟩
Gypsum Board	🟧
XPS Insulation	🟪

Figure 32: Stratton Wall THERM Component Blocks

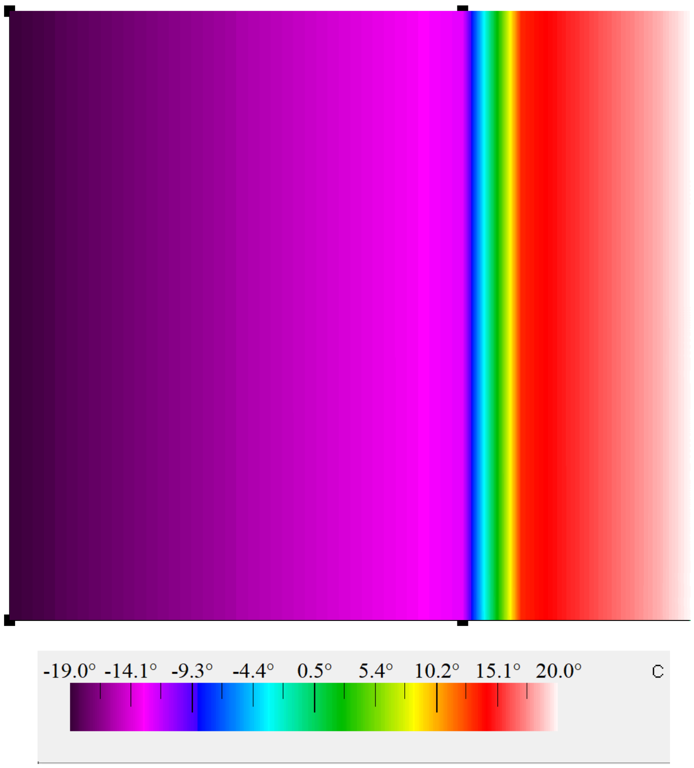
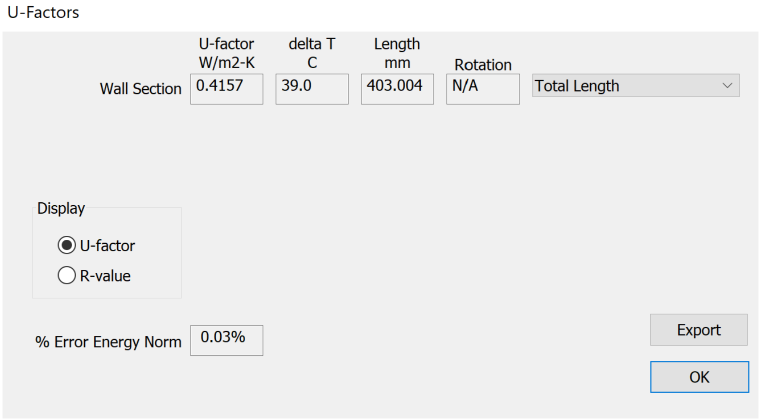


Figure 33: Stratton Wall THERM Thermal Gradient


U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Wall Section	0.4157	39.0	403.004	N/A	Total Length

Display

● U-factor
○ R-value

% Error Energy Norm 0.03%

Figure 34: Stratton Wall THERM Calculated U-Value

Based on Figure 32, 33, and 34 we can determine that the wall section meets the prescribed energy code of 0.51 (W/(m²·°C)) found in Table 2.

Material	Color
Hardwoods	🟫
XPS Insulation	🟪
Gravel	🟩
Dirt	🟫
Concrete	⬜
Wood Flooring	🟨

Figure 35: Stratton Floor THERM Component Blocks

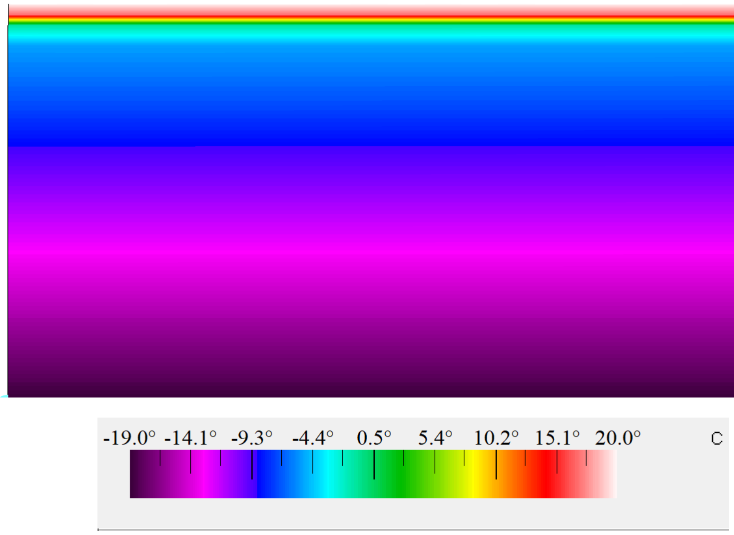
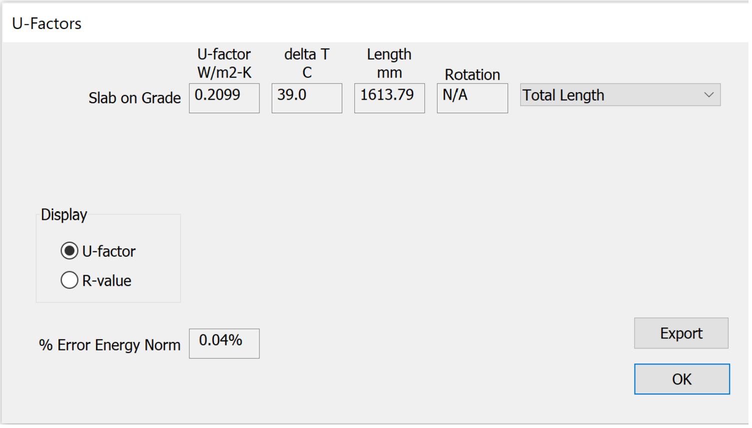


Figure 36: Stratton Floor THERM Thermal Gradient



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Slab on Grade	0.2099	39.0	1613.79	N/A	Total Length

Display

● U-factor

○ R-value

% Error Energy Norm 0.04%

Figure 37: Stratton Floor THERM Calculated U-Value

Based on Figure 35, 36, and 37 we can determine that the slab on grade meets the code requirements set at 0.32 (W/(m²·°C)) found in Table 2.

Overall our designs proved that our retrofit design successfully met and exceeded US energy code, mitigated heat loss and prevented thermal bridging within the assemblies.

Energy Analysis

Figure 38 shows the breakdown in EUI of Stratton Hall as it was retrofitted. All the way to the left with an EUI of 183 kWh/m²/yr, is the starting point we used. This was discussed earlier to be modeled as how the building was originally built with mass masonry and single glazed windows. Each of the following blue bars indicate a feature that was changed individually in descending order from least effective to most effective.. This was done to gauge which changes had the largest impact by themselves. The last blue bar indicates the combination of all the mentioned retrofitting strategies right before adding solar panels or “pre-solar panels.” The three red bars indicate the three benchmarks that were achieved in the retrofit process (Code Compliant, DER, and Net Zero) and what the EUI was when that benchmark was achieved. To reiterate, the code compliant bar is only made up of insulation strategies that were required to meet code requirements. The DER is the result of trying to combine strategies to get past a 50% EUI reduction. Finally, the Net Zero is the end result of combining all strategies in the most efficient possible outcome. Figure 38 is meant to display the impact of each strategy on EUI by itself, as a combination, and as final result. The final EUI was -16 kWh/m²/yr.

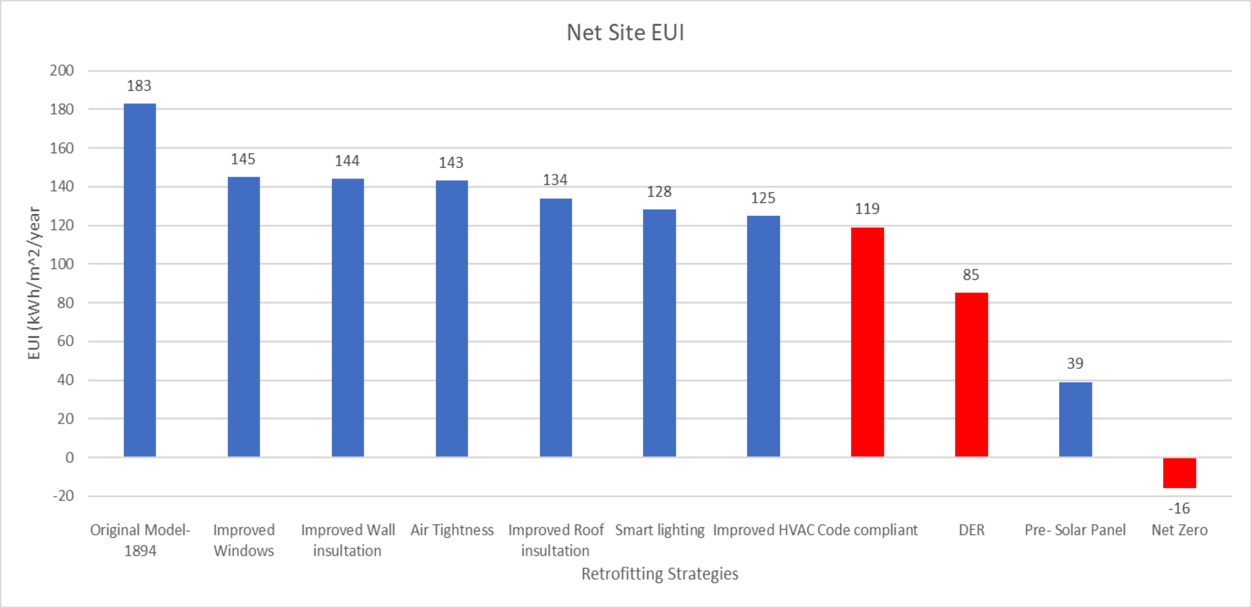


Figure 38: Stratton Hall EUI Breakdown

Lecco Building 12

Code Compliance Analysis

Examining energy code compliance for Building 12 starts with first understanding the EU's goals and strategies to improve the depth of energy retrofits and the rate at which they are occurring. The EU has provided broad guidelines for most of the 21st century but now they are just beginning to enforce stricter, more specific regulations in the building energy efficiency sector. This change will be taken in stride, however, by countries such as Italy that have had one of the highest rates of energy renovations in recent history. The stringent code enforced by regional directives, backed with government approved energy design softwares were essential in creating an energy-efficient retrofit design for Building 12.

Following the Italian Legislative Directive 192/2005 the national standard for estimating the energy performance of buildings UNI/TS 11300 was created. This technical standard is the basis for energy code compliance in the region of Lombardy and sets up the standards for the reference building as discussed previously.

Beginning with the opaque building elements the software THERM was used similarly to how it was used in Stratton Hall to determine the U-Value different elements of the design This will be discussed in the upcoming section on “Heat Transfer Analysis.”

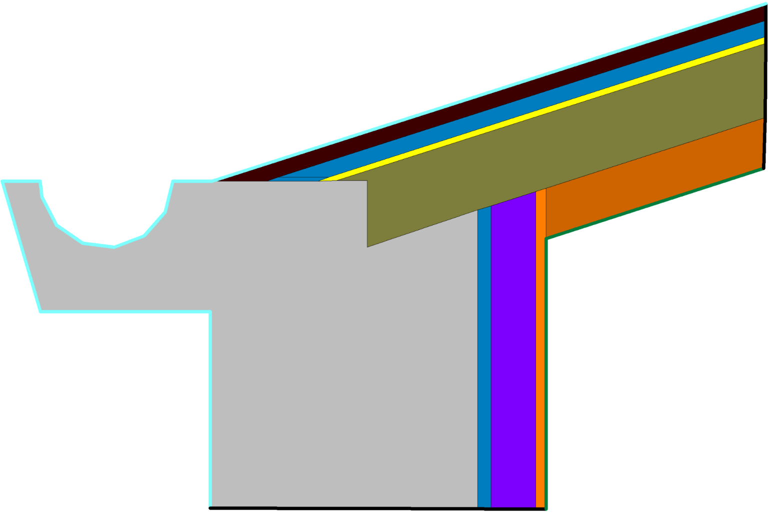
The following restrictions set by the national standard are most often completed using a government authorized free or paid software, however due to language limitations the calculations were done by hand and thus must be considered estimates. To begin we needed to calculate the surface to volume ratio (S/V) and mean heat transfer coefficient denoted as H'_T (W/m^{2}C) using the THERM calculated U-Values for each element analyzed. This calculation can be found in Appendix B and determined that the building meets code with a H'_T of 0.3261 (W/m^{2}C). The next standard we met was the summer effective collecting area which can be found in Appendix B.

As we looked towards standards in heating and cooling the requirements for systems revolved around the efficiencies of those systems. This allowed us to match our HVAC system to Table 8 and confirm that systems used in the Design Builder met the minimum efficiency requirements. The efficiencies set in the simulation software can be found in Appendix C.

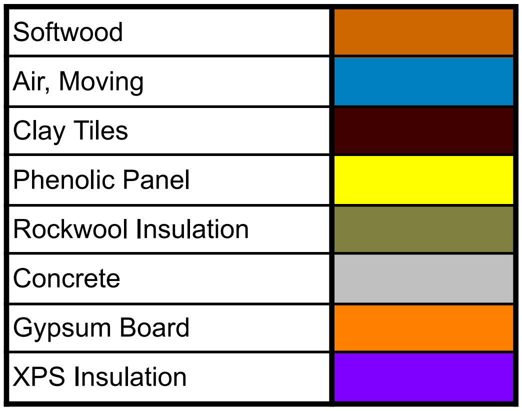
Heat Transfer Analysis

After completing the initial detailing as previously outlined, our focus shifted to examining the heat transfer characteristics of the elements under review. Employing THERM, we modeled the essential aspects that could contribute to thermal bridging or poor thermal performance within the building's structure. This enabled us to assess the potential for thermal bridging and calculate a precise U-Value for the building envelope components, essential for complying with energy codes. By referring to the data in Appendix X, we accurately incorporated the relevant thermal conductivity and emissivity values for the materials in our design. This process provided an overall view of the building assembly's thermal behavior.

We then directed our attention to critical connections in our design, such as the wall to roof and wall to foundation, to investigate heat transfer. Our analysis included identifying thermal bridges, observing temperature distribution, and pinpointing any thermal inefficiencies within the assembly.



Material	Color



Softwood	🟧
Air, Moving	🟦
Clay Tiles	🟫
Phenolic Panel	🟨
Rockwool Insulation	🟫
Concrete	⬜
Gypsum Board	🟧
XPS Insulation	🟪

Figure 39: Building 12 Wall to Roof THERM Component Blocks

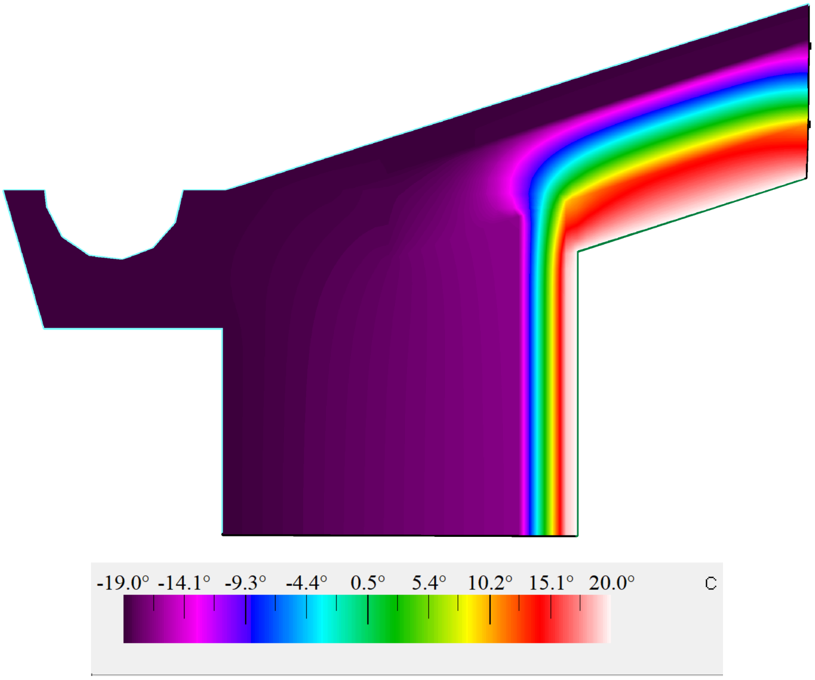
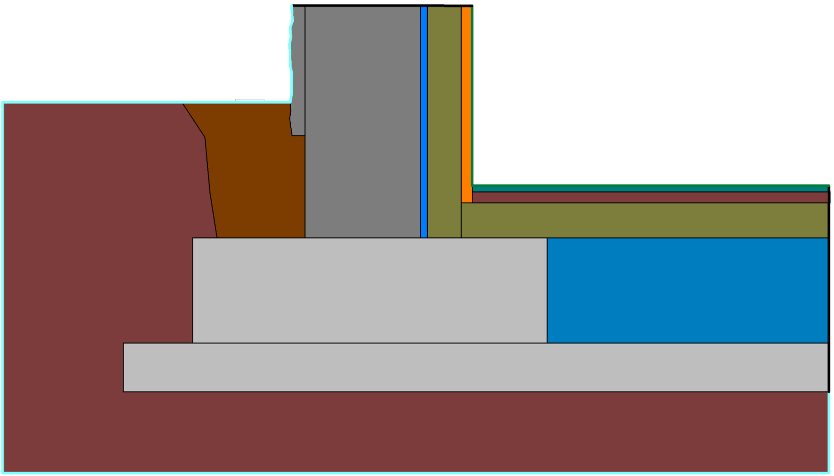


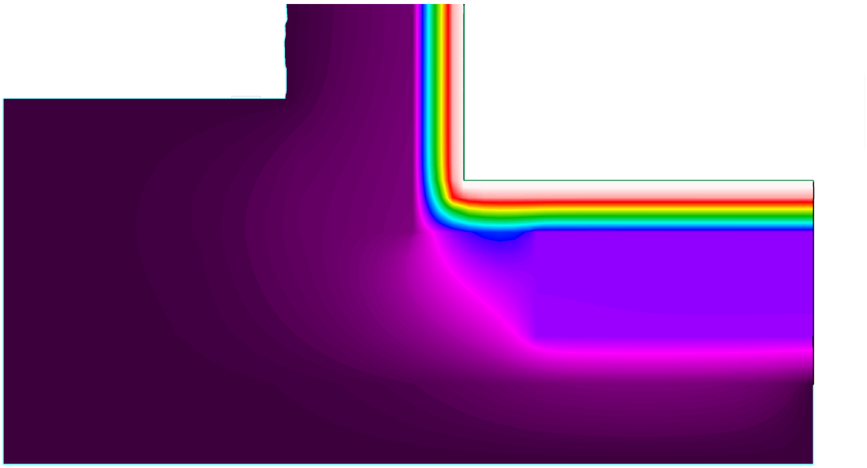
Figure 40: Building 12 Wall to Roof THERM Thermal Gradient

Based on Figure 40 we can determine that there is no thermal bridging in the simplistic wall to roof connection.



Material	Color
Granite	⬛
Soft Dirt	🟫
Dirt	🟫
Concrete	⬜
Air, Moving	🟦
Rockwool Insulation	🟩
Tile Flooring	🟩
Gypsum Board	🟧
Hardwoods	🟫

Figure 41: Building 12 Wall to Foundation THERM Component Blocks



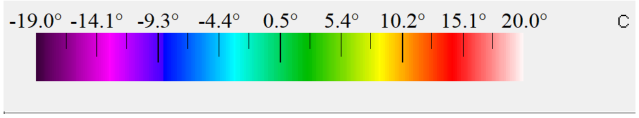
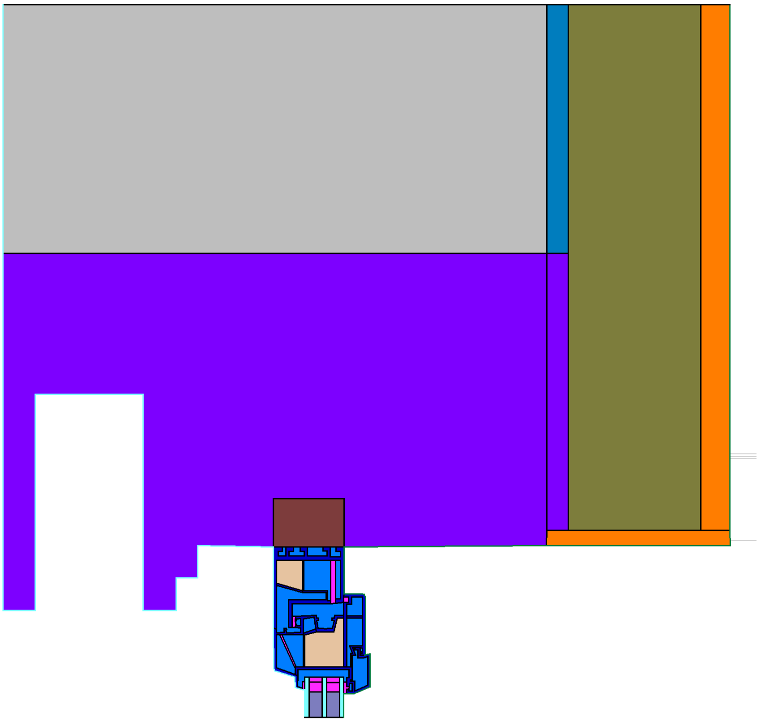


Figure 42: Building 12 Wall to Foundation THERM Thermal Gradient

Based on Figure 42 we can determine that the wall to foundation is sufficient in its ability to prevent heat transfer from the outside to the inside. There is no thermal bridging visible which allows us to make a safe assumption the design is acceptable.

Once we looked at the connections for the building we used the software to examine both the window sill and head to confirm the manufacturer's stated U-Value and look for thermal bridging in the assembly.



Material	Color
Gypsum Board	🟧
Hardwoods	🟫
XPS Insulation	🟪
Air	🟦
Aluminum Frame	🟦
Glass	🟦
Air, Argon	🟪

Silicone	🟪
XPS w CFC and HCFC	🟫
Rockwool Insulation	🟩
Concrete	⬜

Figure 43: Building 12 Window Head THERM Component Blocks

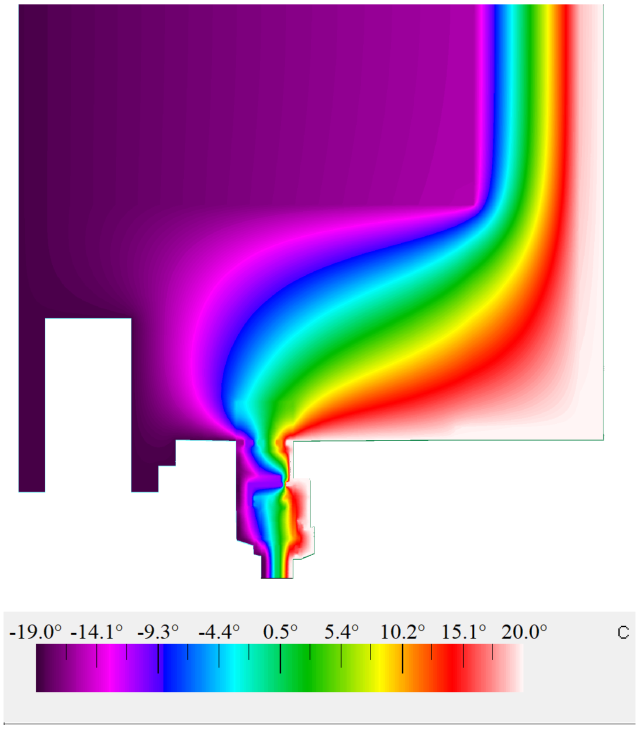
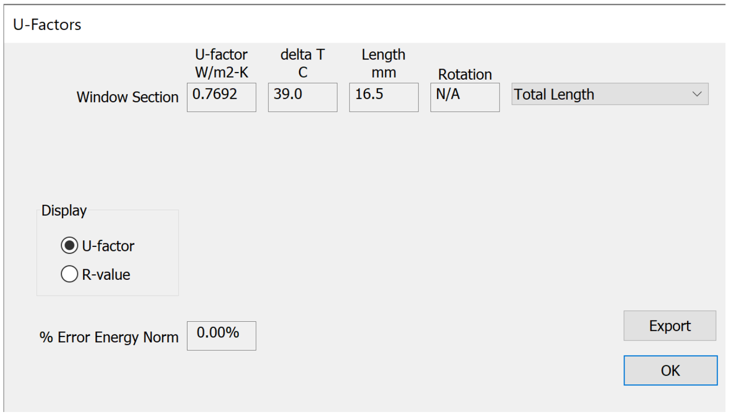


Figure 44: Building 12 Window Head THERM Thermal Gradient



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Window Section	0.7692	39.0	16.5	N/A	Total Length

Display

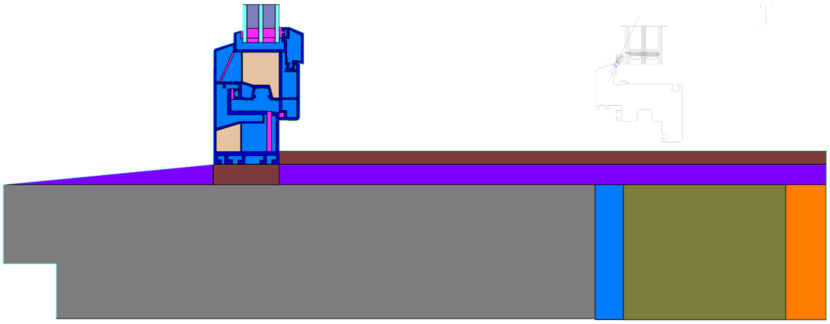
● U-factor

○ R-value

% Error Energy Norm 0.00%

Figure 45: Building 12 Window Head THERM Calculated U-Value

Based on Figure 43, 44, and 45 we can determine that the window is sufficient when compared to the code. The U-Value again differs from the manufacturer's calculated U-Value of 0.73 due to the differences in simulation settings however it meets the prescribed energy code of 1.4 (W/(m²·°C)) found in Table 5.



Material	Color
Gypsum Board	🟧
Hardwoods	🟫
XPS Insulation	🟪
Air	🟦
Aluminum Frame	🟦
Glass	🟦
Air, Argon	🟪
Silicone	🟪
XPS w CFC and HCFC	🟨
Rockwool Insulation	🟩
Concrete	⬜

Figure 46: Building 12 Window Sill THERM Component Blocks

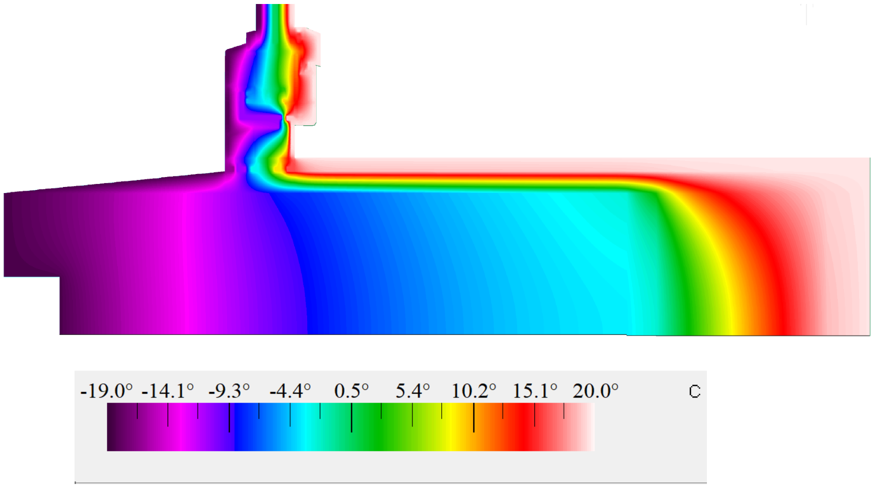
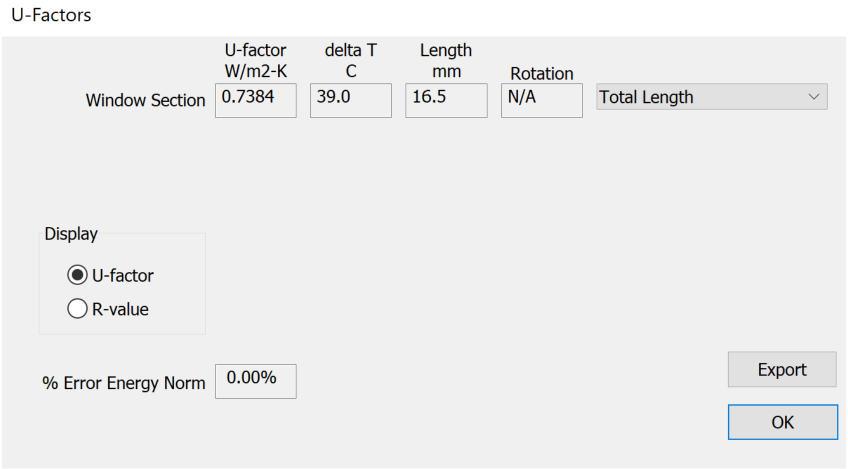


Figure 47: Building 12 Window Sill THERM Thermal Gradient


U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Window Section	0.7384	39.0	16.5	N/A	Total Length

Display

● U-factor

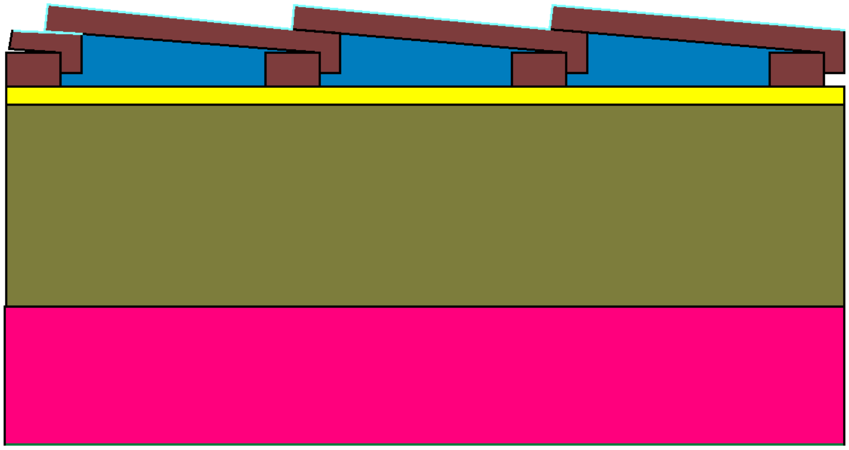
○ R-value

% Error Energy Norm 0.00%

Figure 48: Building 12 Window Sill THERM Calculated U-Value

Based on Figure 46, 47, and 48 we can determine that the window is sufficient when compared to the code. The U-Value again differs from the manufacturer's calculated U-Value of 0.73 due to the differences in simulation settings however it meets the prescribed energy code of 1.4 (W/(m²·°C)).

Finally to confirm that our retrofit design met Italian energy code compliance we used the software to determine the U-Value of the roof, wall and floor assemblies. The heat analysis done on these elements is shown below with the corresponding software calculated U-Value.



Material	Color
Structural Panel	🟪
Air, Moving	🟦
Clay Tiles	🟫

Phenolic Panel	🟨
Rockwool Insulation	🟫

Figure 49: Building 12 Roof THERM Component Blocks

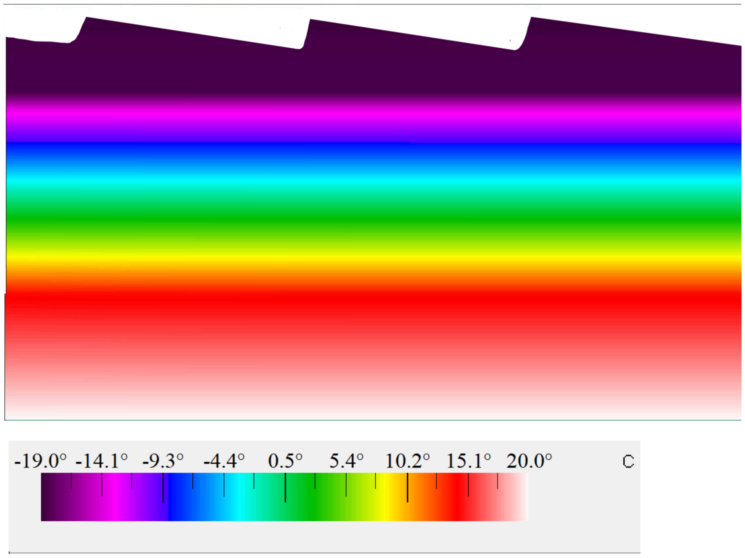
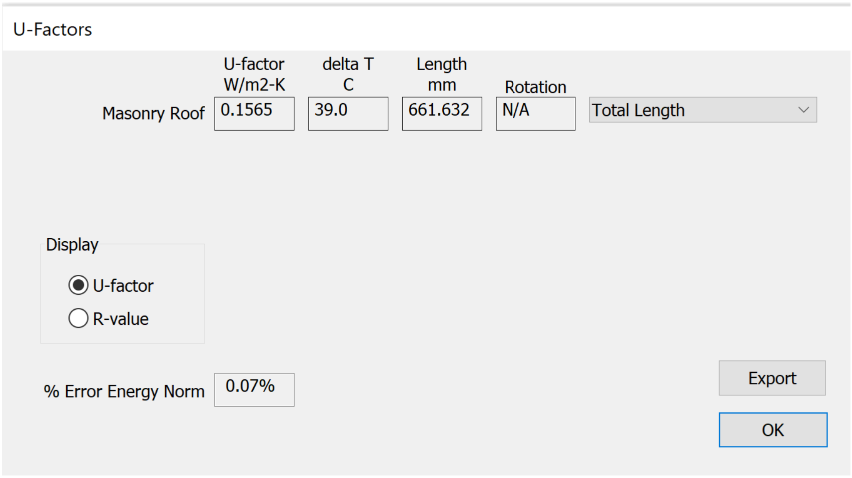


Figure 50: Building 12 Roof THERM Thermal Gradient



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Masonry Roof	0.1565	39.0	661.632	N/A	Total Length

Display

● U-factor

○ R-value

% Error Energy Norm 0.07%

Figure 51: Building 12 Roof THERM Calculated U-Value

Based on Figures 49, 50, and 51 we can determine that our roof section design met the maximum energy code of 0.22 (W/(m²·°C)) found in Table 5.

Material	Color
Granite	⬛
Concrete	⬜
Rockwool Insulation	🟩
Gypsum Board	🟧
Air	++

Figure 52: Building 12 Wall THERM Component Blocks

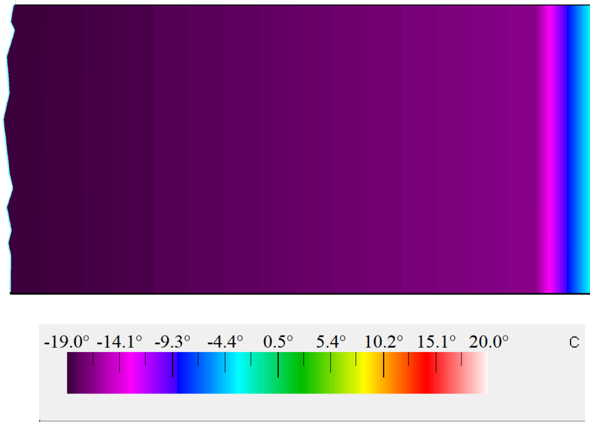
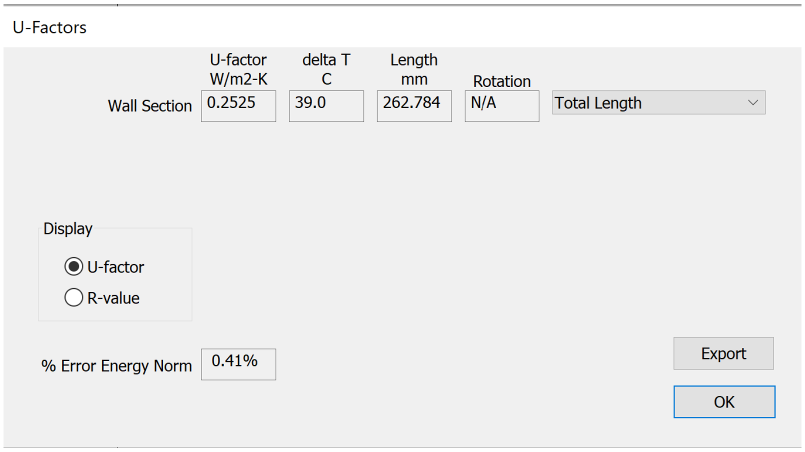


Figure 53: Building 12 Wall THERM Thermal Gradient



	U-factor W/m2-K	delta T C	Length mm	Rotation	
Wall Section	0.2525	39.0	262.784	N/A	Total Length

Display

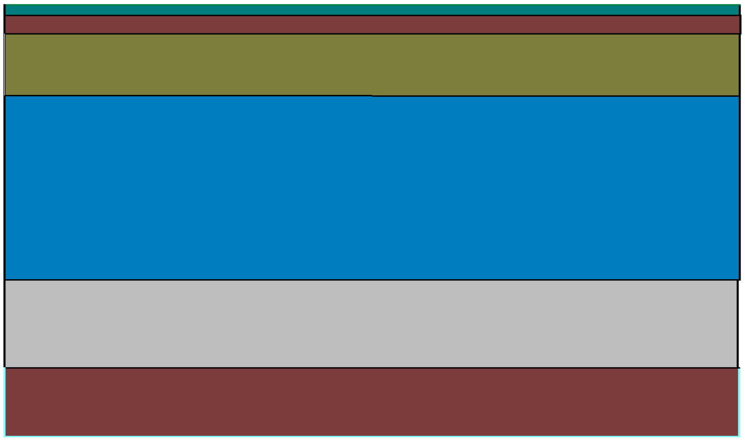
● U-factor

○ R-value

% Error Energy Norm 0.41%

Figure 54: Building 12 Wall THERM Calculated U-Value

Based on Figures 52, 53, and 54 we can determine that although our wall section was close to energy code we still were able to be below the maximum U-Value set forth as stated in Table 5 as 0.26 (W/(m²·°C)).. This design shows that there is a need for more insulation in other opaque elements in other areas of the building to counter the walls.



Material	Color
Hardwoods	🟫
Concrete	⬜
Air, Moving	🟦
Rockwool Insulation	🟩
Tile Flooring	🟦
Dirt	🟫

Figure 55: Building 12 Floor THERM Component Blocks

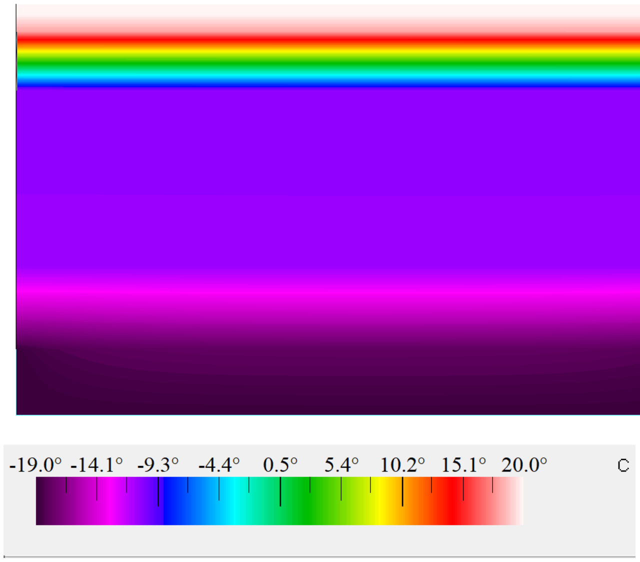
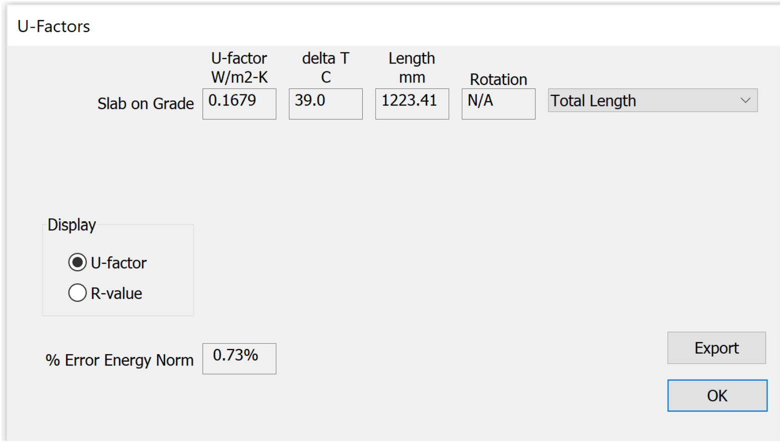


Figure 56: Building 12 Floor THERM Thermal Gradient



U-Factors

	U-factor W/m2-K	delta T C	Length mm	Rotation	
Slab on Grade	0.1679	39.0	1223.41	N/A	Total Length

Display
● U-factor
○ R-value

% Error Energy Norm 0.73%

Figure 57: Building 12 Floor THERM Calculated U-Value

Based on Figures 55, 56, and 57 we can determine that the floor section exceeded the energy code of 0.26 (W/(m²·°C)). Overall our designs proved that our retrofit design successfully met and exceeded Italian energy code, mitigated heat loss and prevented thermal bridging within the assemblies.

Energy Analysis

Figure 58 shows the breakdown in EUI of Stratton Hall as it was retrofitted. All the way to the left with an EUI of 149 kWh/m²/yr, is the starting point we used. This was discussed earlier to be modeled as how the building was originally built with mass masonry and single glazed windows. Each of the following blue bars indicate a feature that was changed individually in descending order from least effective to most effective. This was done to gauge which changes had the largest impact by themselves. As you can see, by themselves, the strategies do not have much of an impact like they did on Stratton. This is theorized to be the larger scale and changing geometry of the building. The last blue bar indicates the combination of all the mentioned retrofitting strategies right before adding solar panels or "pre-solar panels." The three red bars indicate the three benchmarks that were achieved in the retrofit process (Code Compliant, DER, and Net Zero) and what the EUI was when that benchmark was achieved. To reiterate, the code compliant bar is only made up of insulation strategies that were required to meet code requirements. The DER is the result of trying to combine strategies to get past a 50% EUI reduction. Finally, the Net Zero is the end result of combining all strategies in the most efficient possible outcome. Figure 58 is meant to display the impact of each strategy on EUI by itself, as a combination, and as final result. The final EUI was -6 kWh/m²/yr.

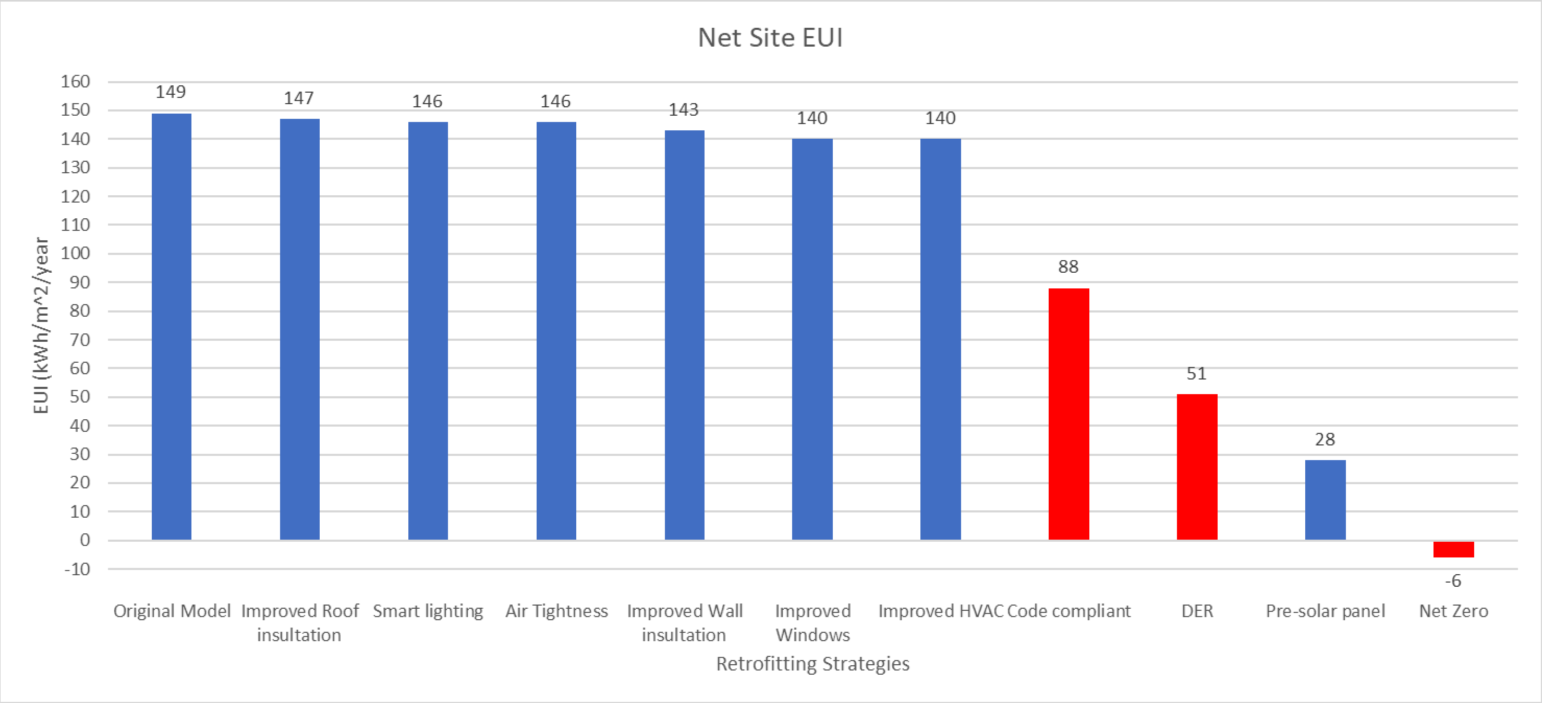


Figure 58: Building 12 EUI Breakdown

Discussion

Cost Effectiveness

This study focused on the strategies to retrofit an old existing masonry building so that it could become a Net Zero building. In doing so, we considered the effectiveness of materials based on their U-Value, the efficiency of systems, construction feasibility, and the space required to achieve the retrofit. It can be seen that we did not factor in the costs of anything in this process. This poses an interesting discussion point, because even though we achieved the energy goals we wanted, how much would it cost to actually make happen. This is an important factor to consider because it is a give and take. Higher end materials may have been chosen due to their superior performance, but that means the financial cost would also increase. The retrofit scenario we have presented above to achieve Net Zero is in fact possible, it would just take a significant amount of money to accomplish due to the high efficiency HVAC systems, number of added insulating materials, high end windows, new lighting, etc. therefore this research could be extend to analyze what retrofitting strategies are most cost effective while still improving efficiency.

Sustainability Strategies Effectiveness

The strategies employed by Europe and the United States to address climate change and reduce GHG emissions reflect differing approaches that have led to varying degrees of success. Both bodies have agreed upon international goals to slow the stop of global warming but the effectiveness of policies to reach these goals have led to different outcomes.

The United States, since its commitment to the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, has had a rocky path in its climate policy. The initial agreement under the UNFCCC was successful, acknowledging the need to address rising carbon emissions. However, the US's view of the issue changed with the Kyoto Protocol in 1997. The withdrawal from the Protocol under President Bush, allowed for voluntary measures by companies that were encouraged over mandatory emission reductions. This approach aimed at reducing the intensity of GHG emissions relative to economic growth rather than absolute emission cuts. By 2005, the US saw its peak emissions at 5,747,310 kilotons of carbon dioxide and 7,477,360 kilotons of GHG. Although a 14% reduction from this peak was achieved by 2016, the EU has shown greater progress in that time.

With a much more aggressive and regulatory approach towards reducing GHG emissions, the EU, since 1990, has managed to reduce its GHG emissions by 30%. This significant decrease from 4,658,202 kilotons in 1990 to 3,241,715 kilotons in 2021 has been the result of comprehensive policies, regulatory frameworks, and investments in renewable energy. With the entire continent of Europe contributing to less than half the amount of GHG emissions into the atmosphere as the US, there should be cause for concern about the stringency of US policies.

With that being said the US has recently made a notable pivot in its climate policy with the adoption of The Inflation Reduction Act after rejoining the Paris Agreement. This act sets ambitious goals for 2030, including reducing GHG emissions by 50-52% below 2005 levels and reaching 100% carbon pollution-free electricity by 2035. The targeted 15% decrease in GHG emissions from 2021 levels marks a significant commitment to addressing climate change, reflecting a more aggressive approach similar to that of the EU.

In the end it is essential that the US remains committed to other world leaders' goals in the globe's battle against climate change. With numbers showing the drastic difference in the emissions reduction between the US and Europe it should be clear that the US needs to adopt similar policies to those in the EU so that we can make greater strides in the sustainability aspect of the building sector.

Conclusion

Future Recommendations

Standardized Practice

Prior to beginning the work on our own modeled buildings in an attempt to reduce EUI, there were a wide range of different strategies to retrofit an old building. The thing that seemed strange though, was the lack of standardization of practiced strategies based on the type of building. It is understood that every building is different and has its own issues, but many old buildings that are in need of renovation were built using some form of masonry, especially in Europe. This presents a way to provide a standard practice solution as a starting point so that it may be brought to a building that needs to be retrofitted and then slightly modified if it is necessary for the building.

In the case of our research on these two masonry buildings, we discovered that at the base level, there are a number of things that can be done to almost any building to improve its energy usage. The starting point should be replacing the windows with higher performing windows. This is the cheapest and easiest to install without greatly affecting the exterior facade of the building since most of the buildings in need of this retrofit are protected as historical buildings and the facade must relatively remain unchanged. It is also an effective way to improve insulation and reduce air leakage without reducing interior space. A high performing window can lessen the need for HVAC systems throughout the year. The next standard practice is dependent on size of the building, cost, and existing conditions, but both should be considered. Insulation should be added on the interior side and the easiest way to do so is add a stud frame against the masonry and stuff it with batt insulation. The other standard practice should be looking at replacing or improving the HVAC. Outdated HVAC systems can be wasting heat and energy. In both retrofit cases we performed, replacing the HVAC with a better, higher efficiency system was the most effective in reducing the EUI of the building by itself. The hardest part about an HVAC system is removing the old system and installing the new one. In conclusion, the practice for retrofitting any old masonry building is to replace the windows with higher performing ones, add insulation inboard by using a stud frame system, and improve or replace the HVAC system.

Energy Class System

One of the greatest strengths the United States has achieved in terms of energy code is its ability to recognize the constant update that code needs to remain effective in the modern world. The standardized system that regularly checks that energy code is still in alignment with international and national goals has created the foundation for a country that is committed to always improving. This, however, should be met with critique as updating energy codes provides the most improvement in new construction. The often overlooked aspect of the building sector is the emissions produced by existing buildings. In the US there are no current checks in place to ensure that the existing building sector continues to upgrade to modernized standards which is why it would be beneficial to establish an energy class system as used in Europe.

The energy class system used in Europe has allowed the continent to create constant checks for not only new buildings but also existing buildings. The system has created a standard that is easily recognizable across the continent as a reliable, effective strategy for consumers and manufacturers alike to better understand environmental sustainability in buildings, appliances and vehicles. By classifying buildings on this scale the US would be able to create a standardized certification process for new and old buildings. Contrary to standards such as U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) or National Association of Home Builders' ICC 700 National Green Building Standard (NGBS) the energy class system is a mandatory EPC that creates a common practice.

Additionally, the energy class system of Europe could be used in the US as a check on the building sector to ensure that energy improvements occur in existing buildings. Repetitive mandatory energy improvements on a percentage of a state’s existing building stock in the lowest energy class would create a system that has a continuous goal of improving the sector. As a country that revolves around comfortable living it is essential that we strive to improve the energy performance of our buildings.

Energy Saving Education

As a country that values comfortable living we do so in an unsustainable way. The cultural differences that exist between the US and Italy are striking and are in part why the US has such higher carbon emissions than Europe in general.

In the U.S., a preference for larger living spaces, more substantial vehicles, and higher overall consumption leads to increased energy usage and carbon emissions. This contrasts with Italian practices, where there is a stronger inclination towards conservation, including smaller homes, less use of air conditioning, and a focus on sustainable living. One of the strongest examples of the conservation of energy comes from the energy code in the country. Part of the code is a requirement that a building “the mass of the external walls (on all sides except northeast to northwest) must exceed 230 kg/m^2, or alternatively, their periodic thermal transmittance YIE must be lower than 0.12 W/m^2K” ("Legislative Decree 192/2005 ANIT DOCUMENT - June 2020"). This regulation creates buildings in the country that have a strong ability to retain their temperature indoors, thus creating less of a need for HVAC systems. This lack of reliance on HVAC creates a population that needs less climate controlled spaces.

Additionally, there are more stringent climate policies and regulations, such as carbon pricing and incentives for renewable energy and energy efficiency. These measures reflect a cultural commitment to environmental sustainability and a collective approach to combating climate change. Meanwhile, the U.S. exhibits a mixed approach to environmental policies, with significant variation between states in their commitment to climate action. The car centric world in which the US exists has created an obvious problem from the environmental sustainability standpoint.

Environmental awareness also plays a crucial role, a deeply ingrained culture of sustainability, influenced by education and public discourse is a key part of the cultural commitment to sustainability. This cultural attitude encourages actions that reduce carbon footprints and prioritize environmental protection. In contrast, while the US has begun to focus more on energy saving education it is still not a cultural shift in the country which is why we are behind Europe in many aspects of sustainability.

Energy saving education plays a crucial role in fostering a culture of sustainability and environmental responsibility. At its core, this form of education seeks to inform individuals and communities about the importance of conserving energy, the benefits of reducing consumption, and the practical steps that can be taken to achieve these goals. The significance of energy saving education is in its potential to effect change at an individual level to the international level.

Acknowledgements

2021 INTERNATIONAL ENERGY CONSERVATION CODE (IECC) | ICC DIGITAL CODES. (2020, December). Codes.iccsafe.org. https://codes.iccsafe.org/content/IECC2021P1/chapter-5-ce-existing-buildings

A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. (2020, October 14). Eur-Lex.europa.eu. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1603122220757&uri=CELEX:52020DC0662

American. (2018). *ASHRAE Standard 100 Energy Conservation in Existing Buildings (ANSI/IESNA Approved)*. https://ashrae.iwrapper.com/ASHRAE_PREVIEW_ONLY_STANDARDS/STD_100_2018

Bronin, S. (2021, April 8). *Aligning Historic Preservation and Energy Efficiency*. Kleinman Center for Energy Policy. https://kleinmanenergy.upenn.edu/research/publications/aligning-historic-preservation-and-energy-efficiency/

Building 12 DWGs. (2020, March 20). POLIMI.

Building Energy Code. (2017). Mass.gov. https://www.mass.gov/info-details/building-energy-code

Campbell, I., & Calhoun, K. (2016, January 21). *Old Buildings Are U.S. Cities' Biggest Sustainability Challenge*. Harvard Business Review. https://hbr.org/2016/01/old-buildings-are-u-s-cities-biggest-sustainability-challenge

Climatic zones. (n.d.). Celsius Panel. Retrieved February 20, 2024, from https://www.celsiuspanel.it/en/climatic-zones/

Crespi, G., Becchio, C., & Corgnati, S. P. (2021). Towards Post-Carbon Cities: Which retrofit scenarios for hotels in Italy? *Renewable Energy*, *163*, 950–963. https://doi.org/10.1016/j.renene.2020.08.023

Davis, K., & Donovan, L. (1997, September 9). *W.P.I. - Stratton Hall*. Mhc-Macris.net. https://mhc-macris.net/queryresults

Deep Energy Retrofits. (n.d.). Www.gsa.gov. Retrieved September 27, 2023, from https://www.gsa.gov/climate-action-and-sustainability/greening-federal-buildings/deep-energy-retrofits

Deptula, E., Delo, M., Hazelton, H., & Bissoondial, A. (2023). Tomorrow's Hurricane Resilient Hub: Designing Modular Shipping Containers in the Mountainous Region of Puerto Rico. : Worcester Polytechnic Institute.

Di Vico, Madison, et al. Building Redevelopment for Repurposing. : Worcester Polytechnic Institute, 2022.

DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on the energy performance of buildings. (2002). https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:001:0065:0071:EN:PDF

DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast). (2010). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0031&from=EN

Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance. (2012, November 14). Official Journal of the European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1399375464230&uri=CELEX:32012L0027

Energy Performance of Buildings Directive. (2023). Eurovent. https://www.eurovent.eu/issues/energyperformanceofbuildings/#visitor-popup

Eu&Me | HOW DOES THE EUROPEAN UNION WORK? (n.d.). Op.europa.eu. https://op.europa.eu/webpub/com/eu-and-me/en/HOW_DOES_THE_EU_WORK.html

European Commission. (2022). *Energy performance of buildings directive*. Energy.ec.europa.eu. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en

European Environment Agency. (2019). *EEA greenhouse gas - data viewer*. European Environment Agency. https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

Facts about Worcester. (2020, March 26). Worcester Historical Museum Library and Archives. https://worcesterhistorical.com/library/facts-about-worcester/

FAQs - National Register of Historic Places (U.S. National Park Service). (n.d.). Www.nps.gov. https://www.nps.gov/subjects/nationalregister/faqs.htm

Greenhouse Gas Inventory Data Explorer | US EPA. (2018, August 18). Cfpub.epa.gov. https://cfpub.epa.gov/ghgdata/inventoryexplorer/#allsectors/allsectors/allgas/econsect/all

Greenhouse Gas Reduction Plan. (2017).

https://www.wpi.edu/sites/default/files/inline-image/Offices/Sustainability/GHG_Plan_WPI_Final2.pdf

Hall, W., Chamber, L., Taylor, S., Helnarski, E., Kurtz, D., Northway, D., Stefani, T., & Andre, V. (2023). *City of Worcester Historical Commission Meeting Agenda 5:30 PM Contacting the Board's Office*. https://www.worcesterma.gov/agendas-minutes/boards-commissions/historical-commission/2023/20230309.pdf

Hausfather, Z. (2017, August 15). *Analysis: Why US carbon emissions have fallen 14% since 2005*. Carbon Brief. https://www.carbonbrief.org/analysis-why-us-carbon-emissions-have-fallen-14-since-2005/

High Performance Thermal Insulation - Thermablok Aerogel. (n.d.). Thermablok - Intelligent Insulation - High Performance Thermal Insulation. https://www.thermablok.co.uk/

History |. (2016). Distretto Metalmeccanico Lecchese. http://www.leccomech.com/en/history/

Iannaccone, G. (2023, October 23). *Campus tour* (F. Ford & S. King, Interviewers) [Personal communication].

Italy's Fifth Progress Report under Directive 2009/28/EC CONTENTS .... 2. (2019). https://wayback.archive-it.org/12090/20220823154832/https://energy.ec.europa.eu/system/files/2020-07/it_-_tr_into_eng_-_5th_progress_report_red_for_2017_and_2018_0.pdf

LBE Priorities and Efforts: High-Performance Efficient Buildings | Mass.gov. (2023). Www.mass.gov.

https://www.mass.gov/info-details/lbe-priorities-and-efforts-high-performance-efficient-buildings

Lecco's history. (2019). EccoLecco. https://www.eccolecco.it/en/lecco-history/

Light and Lighting — Energy Performance of Lighting in Buildings. (2024). Iso.org. https://icontec.isolutions.iso.org/obp/ui#iso:std:iso-cie:20086:ed-1:v1:en

Long-term renovation strategies. (n.d.). Energy.ec.europa.eu. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/long-term-renovation-strategies_en

Low Carbon Technology Strategies SMALL OFFICE. (2021). https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Small_Office_BB_Carbon_Strategies.pdf

Milan Polytechnic - New University Pole in Lecco. (n.d.). Paolo Bodega Architettura. Retrieved October 23, 2023, from http://www.paolobodega.com/en/portfolio/milan-polytechnic-new-university-pole-in-lecco/

Nearly zero-energy buildings. (n.d.). Energy.ec.europa.eu. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/nearly-zero-energy-buildings_en

NREL. (2019). *PVWatts Calculator*. Nrel.gov. https://pvwatts.nrel.gov/pvwatts.php

Office of Alumni Relations. (n.d.). *WPI Tech Bible - The WPI Campus*. Web.wpi.edu. Retrieved September 13, 2023, from https://web.wpi.edu/academics/library/history/techbible/campus.html

Pianigiani, G., & Povoledo, E. (2016, August 27). Quake Exposes Italy's Challenge to Retrofit

Its Architecture. *The New York Times*. https://www.nytimes.com/2016/08/27/world/europe/quake-italy-architecture.html#:~:text=Perhaps%20the%20most%20central%2C%20and

Pittau, F., Malighetti, L. E., Iannaccone, G., & Masera, G. (2017). Prefabrication as Large-scale Efficient Strategy for the Energy Retrofit of the Housing Stock: An Italian Case Study. *Procedia Engineering*, *180*, 1160–1169. https://doi.org/10.1016/j.proeng.2017.04.276

Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 2010/31/EU on the energy performance of buildings. (2016). https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1490877208700&uri=CELEX:52016PC0765

Recommendations. (2016, August 2). European Commission; Official Journal Of The European Union. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016H1318&from=EN

Renewable Energy Portfolio Standard. (2019). Mass.gov. https://www.mass.gov/renewable-energy-portfolio-standard

Renewable energy targets - European Commission. (n.d.). Energy.ec.europa.eu. https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en#:~:text=The%20revised%20Renewable%20Energy%20Directive%20EU%2F2023%2F2413%20raises%20the

Renewable Portfolio Standards | State, Local, and Tribal Governments | NREL. (2013). Nrel.gov. https://www.nrel.gov/state-local-tribal/basics-portfolio-standards.html

Renovation wave. (n.d.). Energy.ec.europa.eu.

https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en

REPowerEU Plan. (2022). https://eur-lex.europa.eu/resource.html?uri=cellar:fc930f14-d7ae-11ec-a95f-01aa75ed71a1.0001.02/DOC_1&format=PDF. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN
PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS.

Rodrigues, F., Parada, M., Vicente, R., Oliveira, R., & Alves, A. (2015). High Energy Efficiency Retrofits in Portugal. *Energy Procedia*, *83*, 187–196. https://doi.org/10.1016/j.egypro.2015.12.209

Salvalai, G., Masera, G., & Sesana, M. M. (2015). Italian local codes for energy efficiency of buildings: Theoretical definition and experimental application to a residential case study. *Renewable and Sustainable Energy Reviews*, *42*, 1245–1259. https://doi.org/10.1016/j.rser.2014.10.038

Shaikh, P. H., Shaikh, F., Sahito, A. A., Uqaili, M. A., & Umrani, Z. (2017, January 1). *Chapter 9 - An Overview of the Challenges for Cost-Effective and Energy-Efficient Retrofits of the Existing Building Stock* (F. Pacheco-Torgal, C.-G. Granqvist, B. P. Jelle, G. P. Vanoli, N. Bianco, & J. Kurnitski, Eds.). ScienceDirect; Woodhead Publishing. https://www.sciencedirect.com/science/article/abs/pii/B9780081011287000095#section-cited-by

STRATEGY FOR ENERGY RETROFITTING OF NATIONAL BUILDING STOCK Italy. (2021).

https://energy.ec.europa.eu/system/files/2021-12/2020_ltrs_italy_-_en.pdf

Stratton Hall | Worcester Polytechnic Institute. (n.d.). Www.wpi.edu. Retrieved September 13, 2023, from https://www.wpi.edu/about/locations/stratton-hall

Sullivan, D. (2019). *New Building Energy Codes : What Do They Mean for Worcester? - Worcester Regional Chamber of Commerce*. Www.worcesterchamber.org. https://www.worcesterchamber.org/new-building-energy-code-s-mean-worcester/

Texts adopted - Energy performance of buildings (recast) - Tuesday, 14 March 2023. (2023, March 14). Www.europarl.europa.eu. https://www.europarl.europa.eu/doceo/document/TA-9-2023-0068_EN.html

The white house. (2021, January 27). *National Climate Task Force*. The White House. https://www.whitehouse.gov/climate/

Total net greenhouse gas emission trends and projections in Europe. (2023, October 24). Www.eea.europa.eu. https://www.eea.europa.eu/en/analysis/indicators/total-greenhouse-gas-emission-trends?activeAccordion=

Welch, S., Obonyo, E., & Memari, A. (2023). A review of the previous and current challenges of passive house retrofits. *Building and Environment*, 110938. https://doi.org/10.1016/j.buildenv.2023.110938

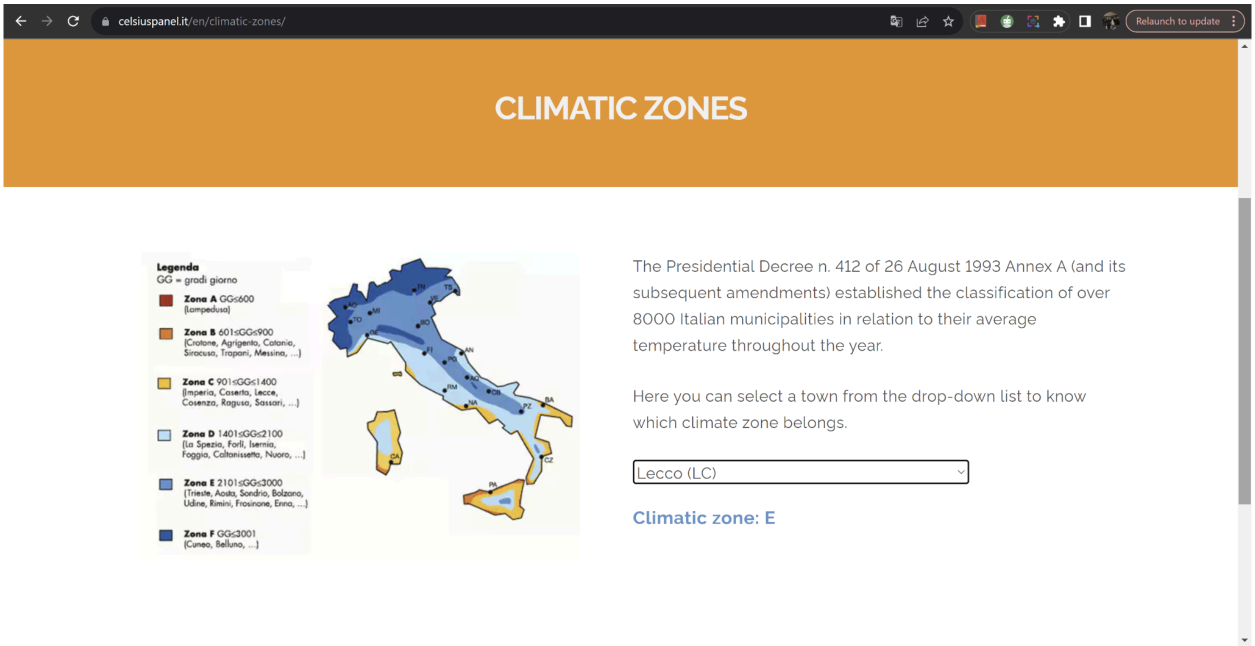
Wilson, A. (2022). *BRIEFING EU Legislation in Progress Proposal for a Regulation of the European Parliament and of the Council on the energy performance of buildings (recast) Ordinary legislative procedure (COD) (Parliament and Council on equal footing - formerly "co-decision") Next steps expected: Appointment of rapporteur*. https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/698901/EPRS_BRI(2022)69

8901_EN.pdf

Wilson, A. (2023). *AT A GLANCE Plenary -March I 2023*. https://www.europarl.europa.eu/RegData/etudes/ATAG/2023/739377/EPRS_ATA(2023)739377_EN.pdf

Appendices

Appendix A: Climatic Zones Of Italy



CLIMATIC ZONES

The Presidential Decree n. 412 of 26 August 1993 Annex A (and its subsequent amendments) established the classification of over 8000 Italian municipalities in relation to their average temperature throughout the year.

Here you can select a town from the drop-down list to know which climate zone belongs.

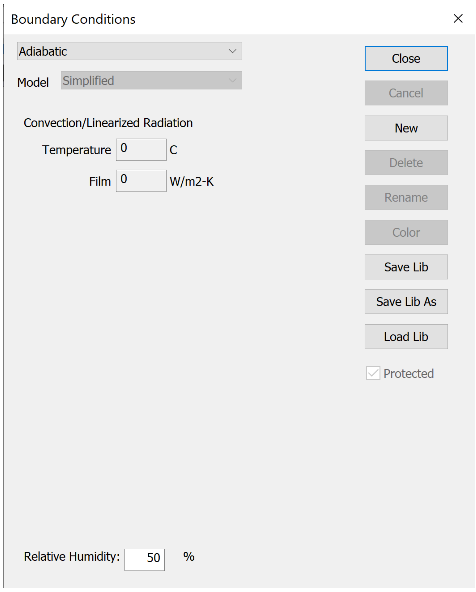
Lecco (LC)

Climatic zone: E

Appendix B: THERM Settings

Table 11: THERM Material Key

Material	Color	Thermal Conductivity (W/(m²·°C))	Emissivity	Source	Material	Color	Thermal Conductivity (W/(m²·°C))	Emissivity	Source
Softwood	🟧	0.11	0.8	THERM	Granite	⬛	2.99	0.9	OSTI.GOV
Fiberglass (PE Resin)	🟦	0.3	0.9	THERM	Soft Dirt	🟫	1.1	0.9	OSTI.GOV
Gypsum Board	🟧	0.2	0.87	THERM	Dirt	🟫	1	0.9	OSTI.GOV
Brick	🟥	0.75	0.9	THERM	Concrete	⬜	0.2	0.9	OSTI.GOV
Hardwoods	🟫	0.16	0.8	THERM	Gravel	🟩	1.2	0.9	OSTI.GOV
XPS Insulation	🟪	0.029	0.9	THERM	Air, Moving	🟦	24	0.9	THERM
Air	🟦	1.01	0.9	THERM	Clay Tiles	🟫	0.7	0.9	OSTI.GOV
Aluminum Frame	🟦	237	0.9	THERM	Phenolic Panel	🟨	0.018	0.9	OSTI.GOV
Silicone	🟪	0.35	0.8	THERM	Rockwool Insulation	🟩	0.035	0.9	THERM
Steel	⬜	45	0.95	THERM	Plaster	🟫	0.5	0.9	THERM
Urethene	🟨	0.12	0.9	THERM	XPS w CFC and HCFC	🟧	0.03	0.9	THERM
Glass	🟦	1	0.1	THERM	Tile Flooring	🟦	10	0.9	OSTI.GOV
Air, Argon	🟪	0.09	0.9	THERM	Wood Flooring	🟨	0.14	0.9	THERM
Structural Panels	🟥	0.1	0.85	THERM	Silicone Foam	🟪	0.17	0.9	THERM



Boundary Conditions

Adiabatic

Model Simplified

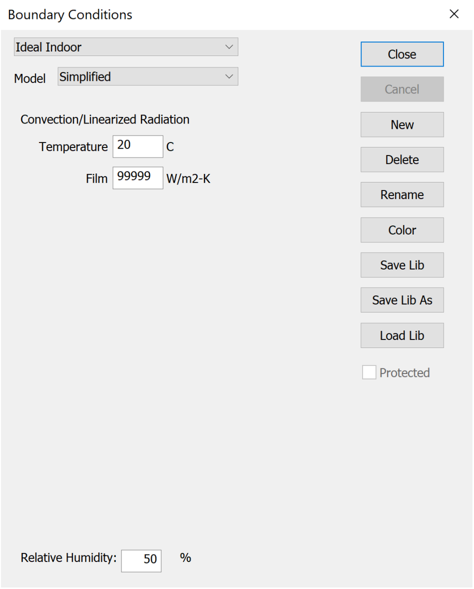
Convection/Linearized Radiation

Temperature 0 C

Film 0 W/m2-K

Relative Humidity: 50 %

☑ Protected



Boundary Conditions

Ideal Indoor

Model Simplified

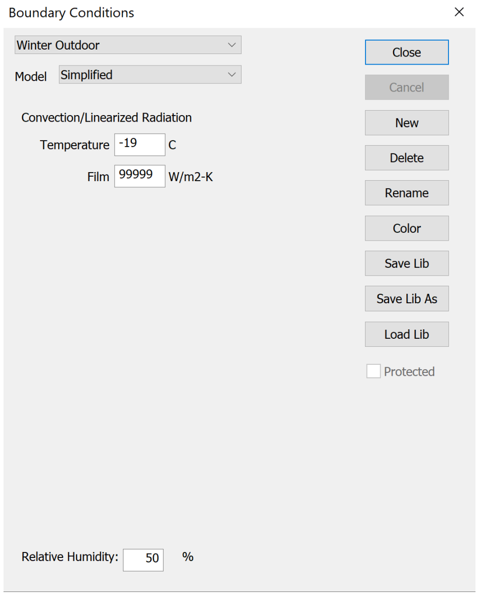
Convection/Linearized Radiation

Temperature 20 C

Film 99999 W/m2-K

Relative Humidity: 50 %

☐ Protected



Boundary Conditions

Winter Outdoor

Model Simplified

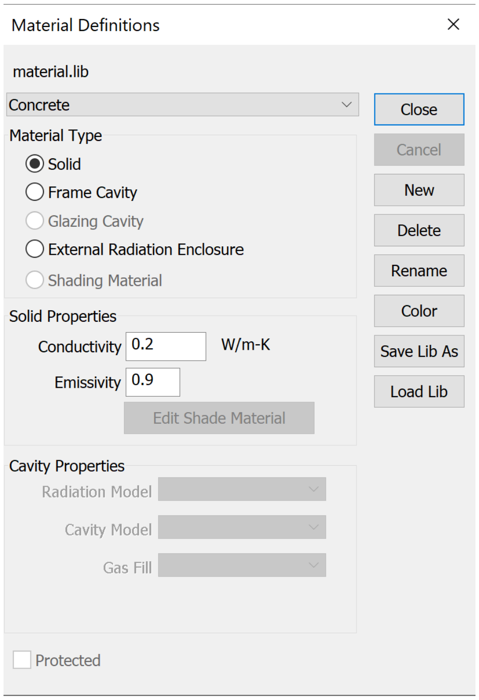
Convection/Linearized Radiation

Temperature -19 C

Film 99999 W/m2-K

Relative Humidity: 50 %

☐ Protected



Material Definitions

material.lib

Concrete

Material Type

● Solid

○ Frame Cavity

○ Glazing Cavity

○ External Radiation Enclosure

○ Shading Material

Solid Properties

Conductivity 0.2 W/m-K

Emissivity 0.9

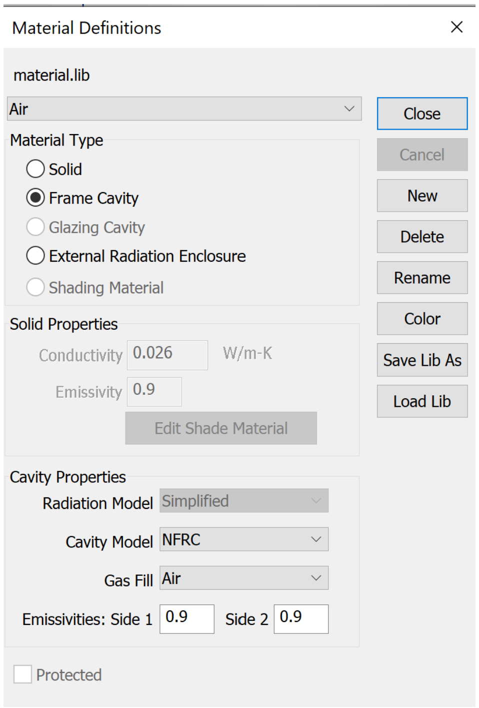
Cavity Properties

Radiation Model

Cavity Model

Gas Fill

☐ Protected



Material Definitions

material.lib

Air

Material Type

○ Solid

● Frame Cavity

○ Glazing Cavity

○ External Radiation Enclosure

○ Shading Material

Solid Properties

Conductivity 0.026 W/m-K

Emissivity 0.9

Cavity Properties

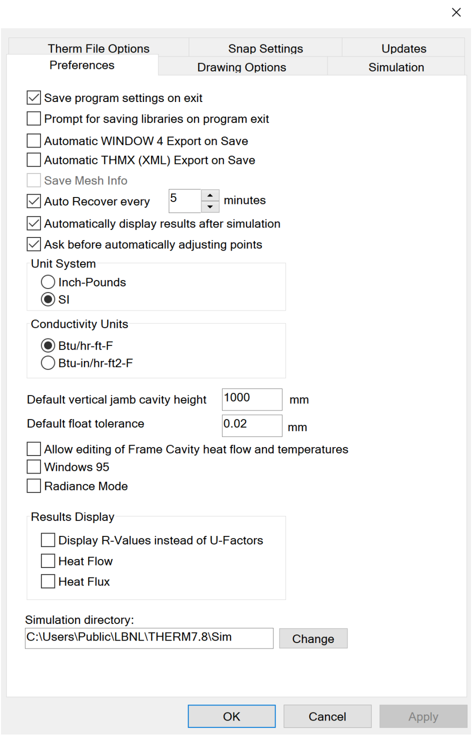
Radiation Model Simplified

Cavity Model NFRC

Gas Fill Air

Emissivities: Side 1 0.9 Side 2 0.9

☐ Protected



☑ Save program settings on exit
☐ Prompt for saving libraries on program exit
☐ Automatic WINDOW 4 Export on Save
☐ Automatic THMX (XML) Export on Save
☐ Save Mesh Info
☑ Auto Recover every 5 minutes
☑ Automatically display results after simulation
☑ Ask before automatically adjusting points

Unit System
○ Inch-Pounds
● SI

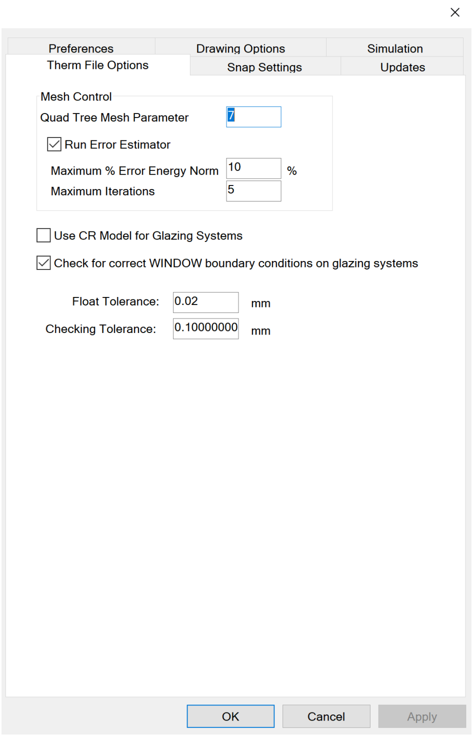
Conductivity Units
● Btu/hr-ft-F
○ Btu-in/hr-ft2-F

Default vertical jamb cavity height 1000 mm
Default float tolerance 0.02 mm

☐ Allow editing of Frame Cavity heat flow and temperatures
☐ Windows 95
☐ Radiance Mode

Results Display
☐ Display R-Values instead of U-Factors
☐ Heat Flow
☐ Heat Flux

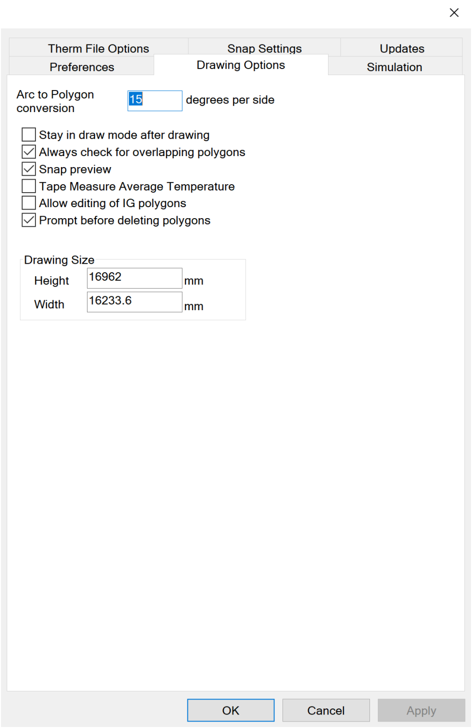
Simulation directory:
C:\Users\Public\LBNL\THERM7.8\Sim



Mesh Control
Quad Tree Mesh Parameter 7
☑ Run Error Estimator
Maximum % Error Energy Norm 10 %
Maximum Iterations 5

☐ Use CR Model for Glazing Systems
☑ Check for correct WINDOW boundary conditions on glazing systems

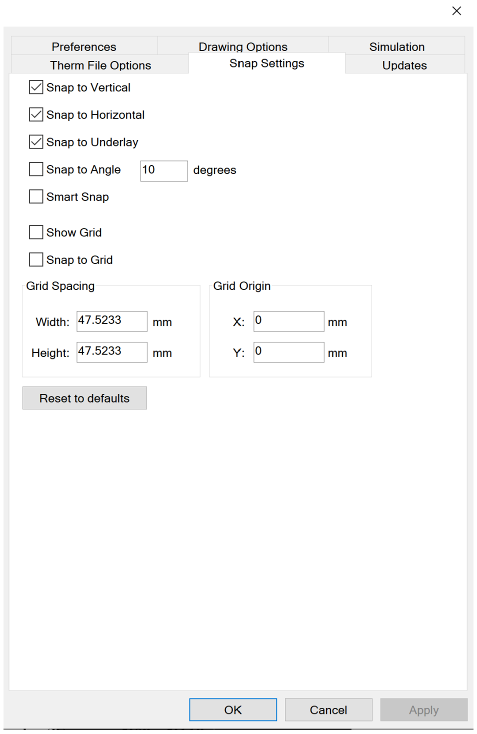
Float Tolerance: 0.02 mm
Checking Tolerance: 0.10000000 mm



Arc to Polygon conversion 15 degrees per side

☐ Stay in draw mode after drawing
☑ Always check for overlapping polygons
☑ Snap preview
☐ Tape Measure Average Temperature
☐ Allow editing of IG polygons
☑ Prompt before deleting polygons

Drawing Size
Height 16962 mm
Width 16233.6 mm

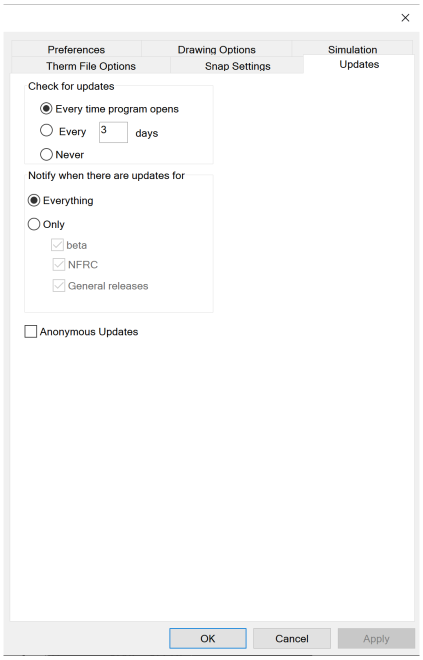


☑ Snap to Vertical
☑ Snap to Horizontal
☑ Snap to Underlay
☐ Snap to Angle 10 degrees
☐ Smart Snap

☐ Show Grid
☐ Snap to Grid

Grid Spacing
Width: 47.5233 mm
Height: 47.5233 mm

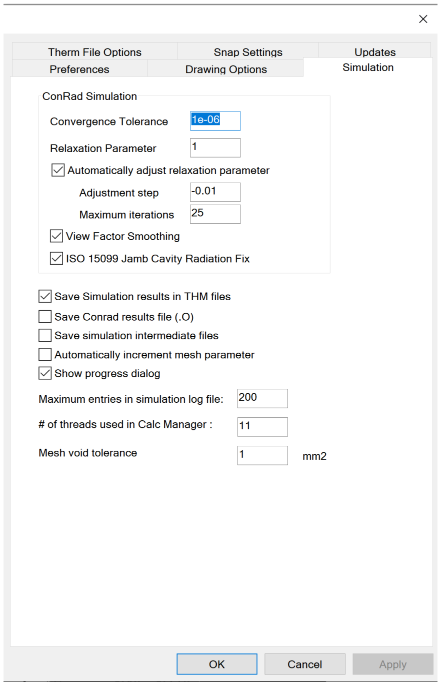
Grid Origin
X: 0 mm
Y: 0 mm



Check for updates
● Every time program opens
○ Every 3 days
○ Never

Notify when there are updates for
● Everything
○ Only
☑ beta
☑ NFRC
☑ General releases

☐ Anonymous Updates



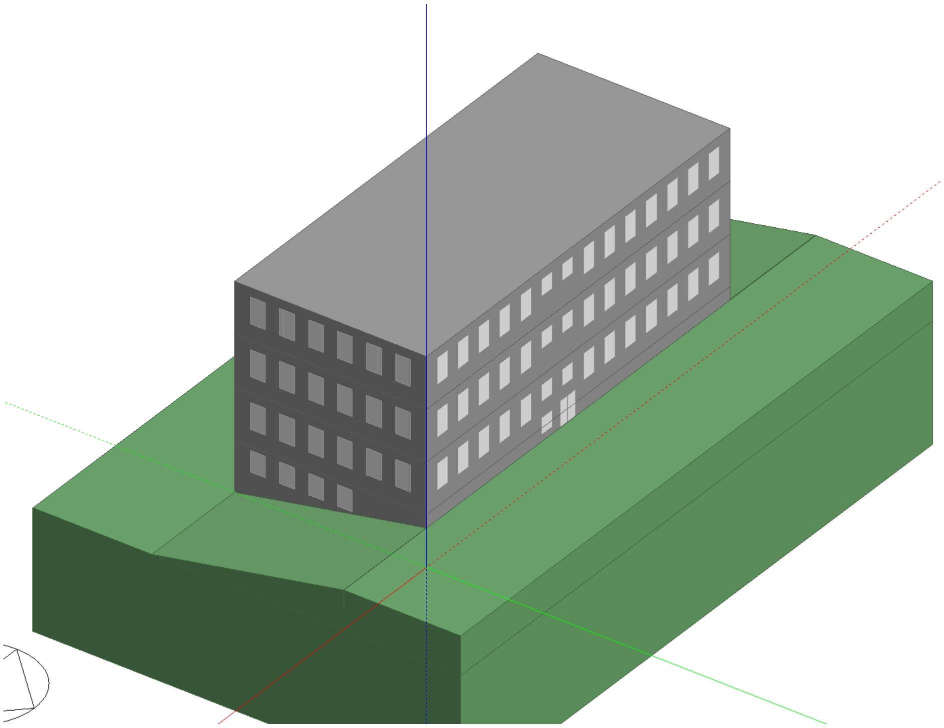
ConRad Simulation
Convergence Tolerance 1e-06
Relaxation Parameter 1
☑ Automatically adjust relaxation parameter
Adjustment step -0.01
Maximum iterations 25
☑ View Factor Smoothing
☑ ISO 15099 Jamb Cavity Radiation Fix

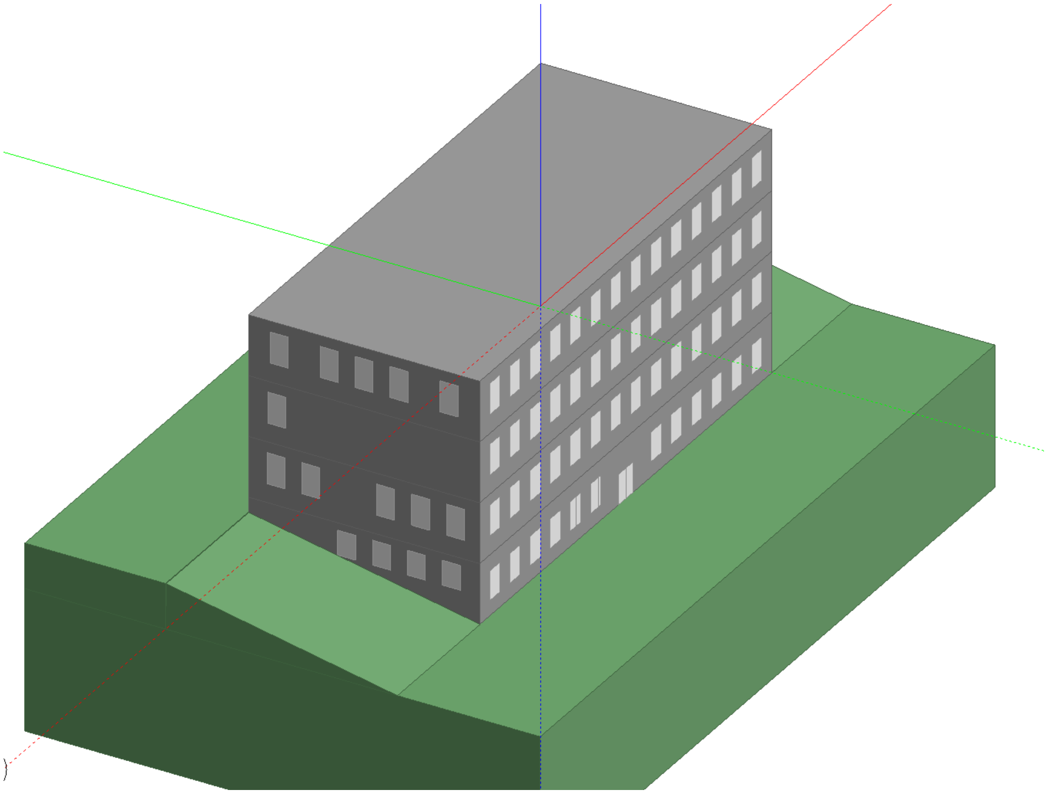
☑ Save Simulation results in THM files
☐ Save Conrad results file (.O)
☐ Save simulation intermediate files
☐ Automatically increment mesh parameter
☑ Show progress dialog

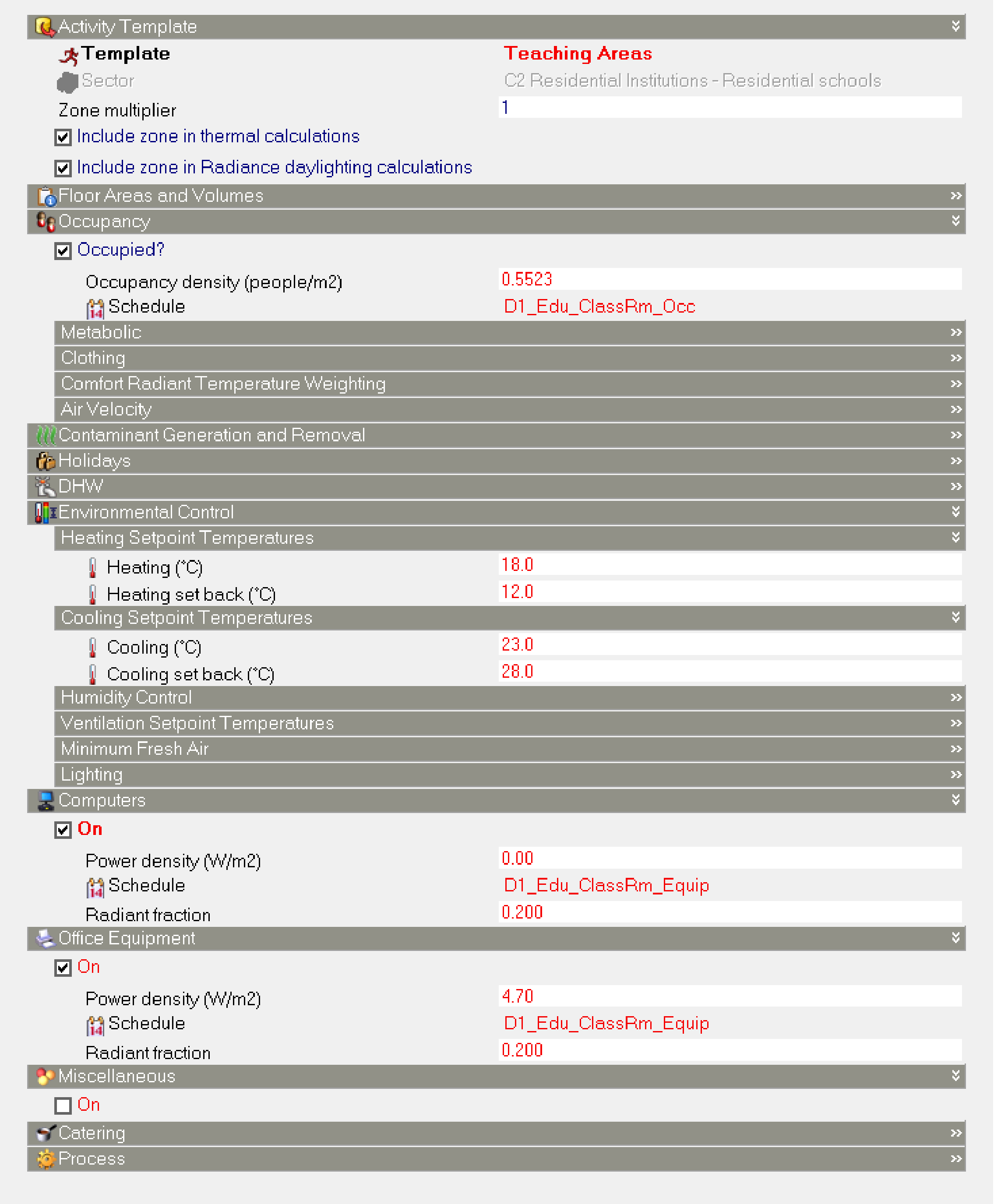
Maximum entries in simulation log file: 200
# of threads used in Calc Manager : 11
Mesh void tolerance 1 mm2

Appendix C: Design Builder Settings

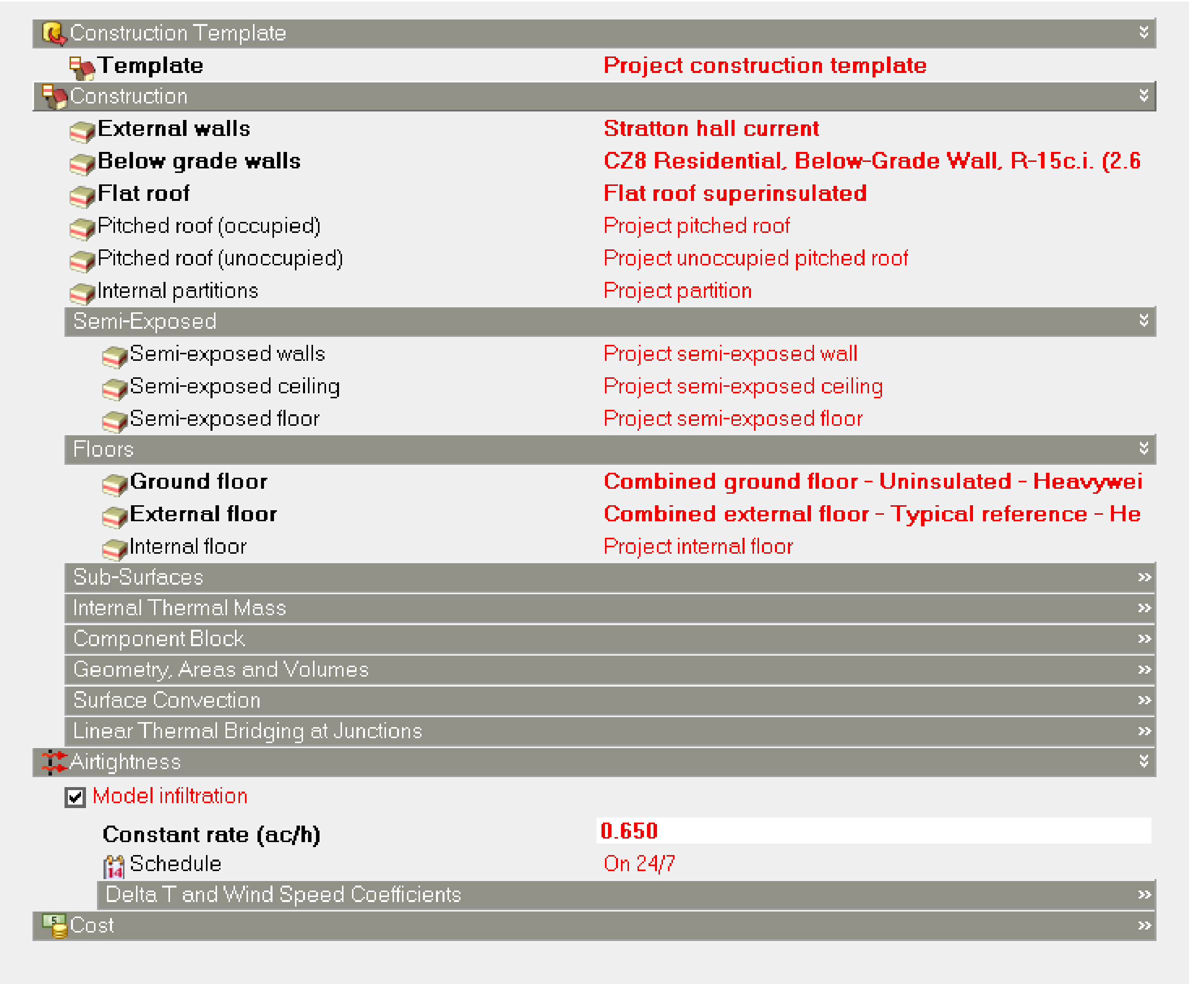
Stratton Hall







Activity Template	
Template	**Teaching Areas**
Sector	C2 Residential Institutions - Residential schools
Zone multiplier	1
☑ Include zone in thermal calculations	
☑ Include zone in Radiance daylighting calculations	
Floor Areas and Volumes	
Occupancy	
☑ Occupied?	
Occupancy density (people/m2)	0.5523
Schedule	D1_Edu_ClassRm_Occ
Metabolic	
Clothing	
Comfort Radiant Temperature Weighting	
Air Velocity	
Contaminant Generation and Removal	
Holidays	
DHW	
Environmental Control	
Heating Setpoint Temperatures	
Heating (°C)	18.0
Heating set back (°C)	12.0
Cooling Setpoint Temperatures	
Cooling (°C)	23.0
Cooling set back (°C)	28.0
Humidity Control	
Ventilation Setpoint Temperatures	
Minimum Fresh Air	
Lighting	
Computers	
☑ **On**	
Power density (W/m2)	0.00
Schedule	D1_Edu_ClassRm_Equip
Radiant fraction	0.200
Office Equipment	
☑ On	
Power density (W/m2)	4.70
Schedule	D1_Edu_ClassRm_Equip
Radiant fraction	0.200
Miscellaneous	
☐ On	
Catering	
Process	



Construction Template

Template	**Project construction template**

Construction

External walls	**Stratton hall current**
Below grade walls	**CZ8 Residential, Below-Grade Wall, R-15c.i. (2.6**
Flat roof	**Flat roof superinsulated**
Pitched roof (occupied)	Project pitched roof
Pitched roof (unoccupied)	Project unoccupied pitched roof
Internal partitions	Project partition

Semi-Exposed

Semi-exposed walls	Project semi-exposed wall
Semi-exposed ceiling	Project semi-exposed ceiling
Semi-exposed floor	Project semi-exposed floor

Floors

Ground floor	**Combined ground floor - Uninsulated - Heavywei**
External floor	**Combined external floor - Typical reference - He**
Internal floor	Project internal floor

Sub-Surfaces

Internal Thermal Mass

Component Block

Geometry, Areas and Volumes

Surface Convection

Linear Thermal Bridging at Junctions

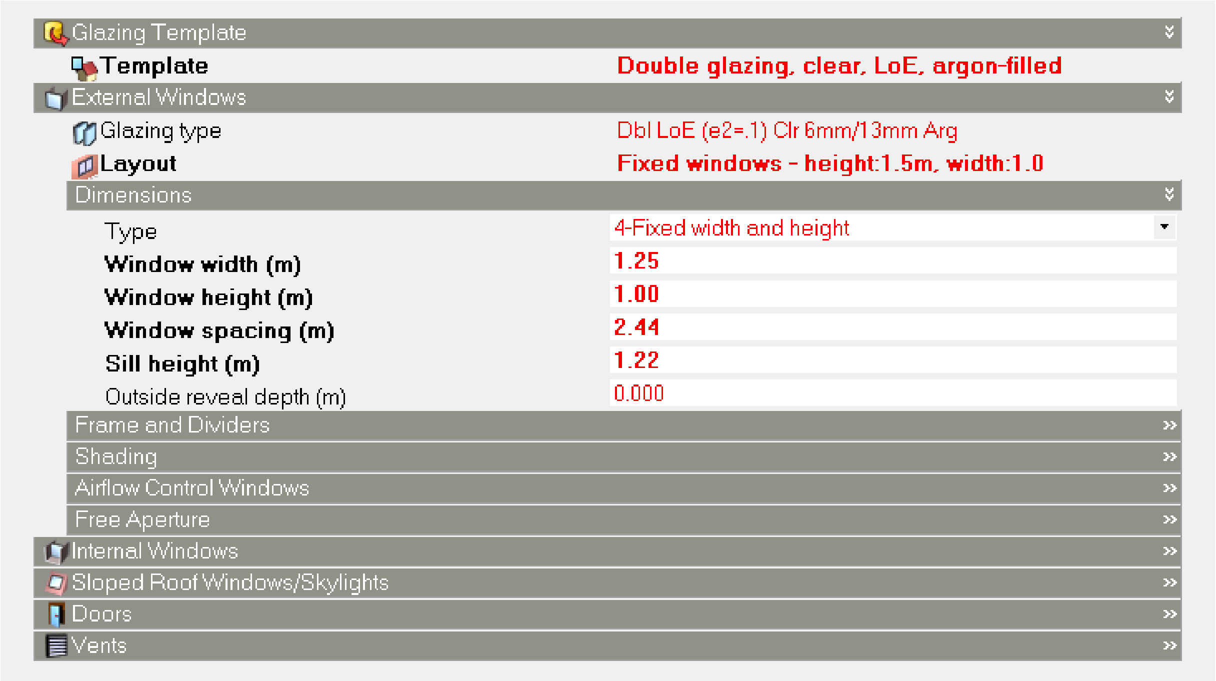
Airtightness

☑ Model infiltration

Constant rate (ac/h)	**0.650**
Schedule	On 24/7

Delta T and Wind Speed Coefficients

Cost



Glazing Template

Template	**Double glazing, clear, LoE, argon-filled**

External Windows

Glazing type	Dbl LoE (e2=.1) Clr 6mm/13mm Arg
Layout	**Fixed windows - height:1.5m, width:1.0**

Dimensions

Type	4-Fixed width and height
Window width (m)	**1.25**
Window height (m)	**1.00**
Window spacing (m)	**2.44**
Sill height (m)	**1.22**
Outside reveal depth (m)	0.000

Frame and Dividers

Shading

Airflow Control Windows

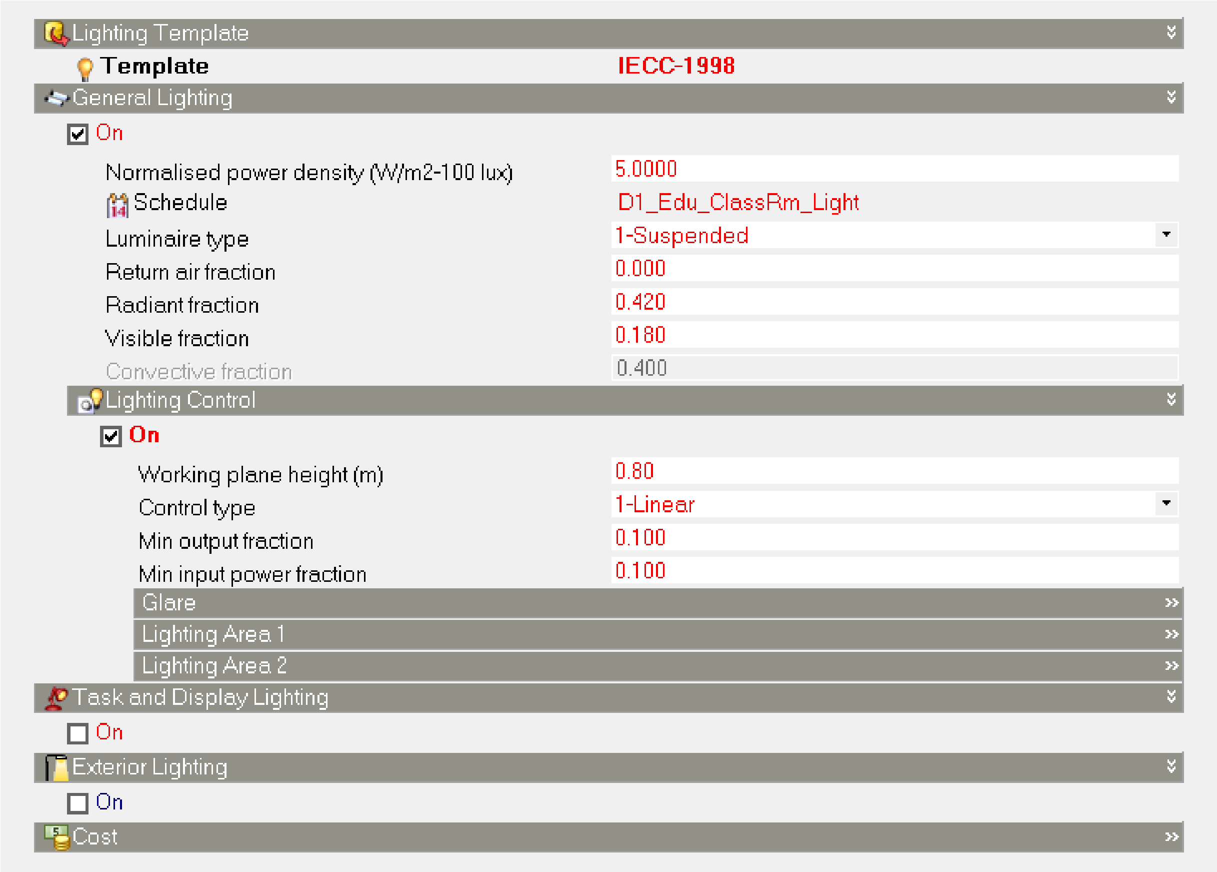
Free Aperture

Internal Windows

Sloped Roof Windows/Skylights

Doors

Vents



Lighting Template

Template: IECC-1998

General Lighting

☑ On

Normalised power density (W/m2-100 lux): 5.0000

Schedule: D1_Edu_ClassRm_Light

Luminaire type: 1-Suspended

Return air fraction: 0.000

Radiant fraction: 0.420

Visible fraction: 0.180

Convective fraction: 0.400

Lighting Control

☑ On

Working plane height (m): 0.80

Control type: 1-Linear

Min output fraction: 0.100

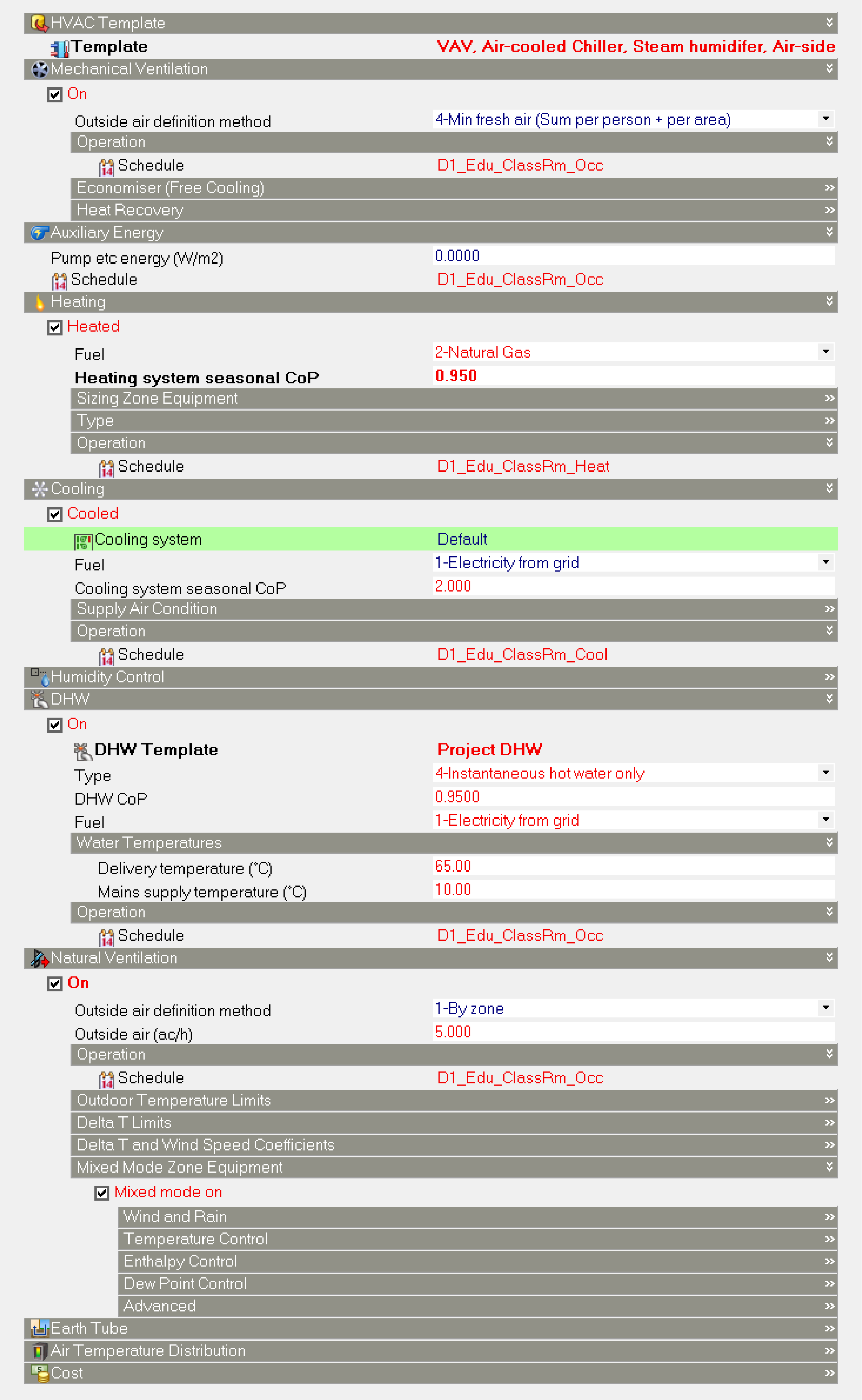
Min input power fraction: 0.100

Task and Display Lighting

☐ On

Exterior Lighting

☐ On



HVAC Template	
Template	**VAV, Air-cooled Chiller, Steam humidifer, Air-side**
Mechanical Ventilation	
☑ On	
Outside air definition method	4-Min fresh air (Sum per person + per area)
Operation	
Schedule	D1_Edu_ClassRm_Occ
Economiser (Free Cooling)	
Heat Recovery	
Auxiliary Energy	
Pump etc energy (W/m2)	0.0000
Schedule	D1_Edu_ClassRm_Occ
Heating	
☑ Heated	
Fuel	2-Natural Gas
Heating system seasonal CoP	**0.950**
Sizing Zone Equipment	
Type	
Operation	
Schedule	D1_Edu_ClassRm_Heat
Cooling	
☑ Cooled	
Cooling system	Default
Fuel	1-Electricity from grid
Cooling system seasonal CoP	2.000
Supply Air Condition	
Operation	
Schedule	D1_Edu_ClassRm_Cool
Humidity Control	
DHW	
☑ On	
DHW Template	**Project DHW**
Type	4-Instantaneous hot water only
DHW CoP	0.9500
Fuel	1-Electricity from grid
Water Temperatures	
Delivery temperature (°C)	65.00
Mains supply temperature (°C)	10.00
Operation	
Schedule	D1_Edu_ClassRm_Occ
Natural Ventilation	
☑ **On**	
Outside air definition method	1-By zone
Outside air (ac/h)	5.000
Operation	
Schedule	D1_Edu_ClassRm_Occ
Outdoor Temperature Limits	
Delta T Limits	
Delta T and Wind Speed Coefficients	
Mixed Mode Zone Equipment	
☑ Mixed mode on	
Wind and Rain	
Temperature Control	
Enthalpy Control	
Dew Point Control	
Advanced	
Earth Tube	
Air Temperature Distribution	
Cost	

General

Name in last EnergyPlus calculation: Building 1

Tag:

Heating Design Output Options

☐ Include unoccupied zones in block and building totals and averages

☐ Store surface output

Cooling Design Output Options

☐ Include unoccupied zones in block and building totals and averages

☐ Store surface output

Simulation Output Options

☑ Building and block output of zone data

☐ Include unoccupied zones in block and building totals and averages

☐ Allow custom outputs

Graphable Outputs

Energy

☐ Surface heat transfer

☑ Internal gains including solar

☑ Energy, HVAC etc

☑ Latent loads

Comfort and Environmental

☑ Environmental

☑ Fresh air supply

☐ Simple ASHRAE Standard 55

☐ Adaptive ASHRAE Standard 55

☐ Adaptive CEN Standard 15251

☐ CIBSE TM52

☐ CIBSE TM59

☐ Fanger

☐ Pierce two-node

☐ Kansas State University two-node

☐ Temperature distribution

Building Surface and Opening Outputs

☐ Store surface output

Summary Annual Reports

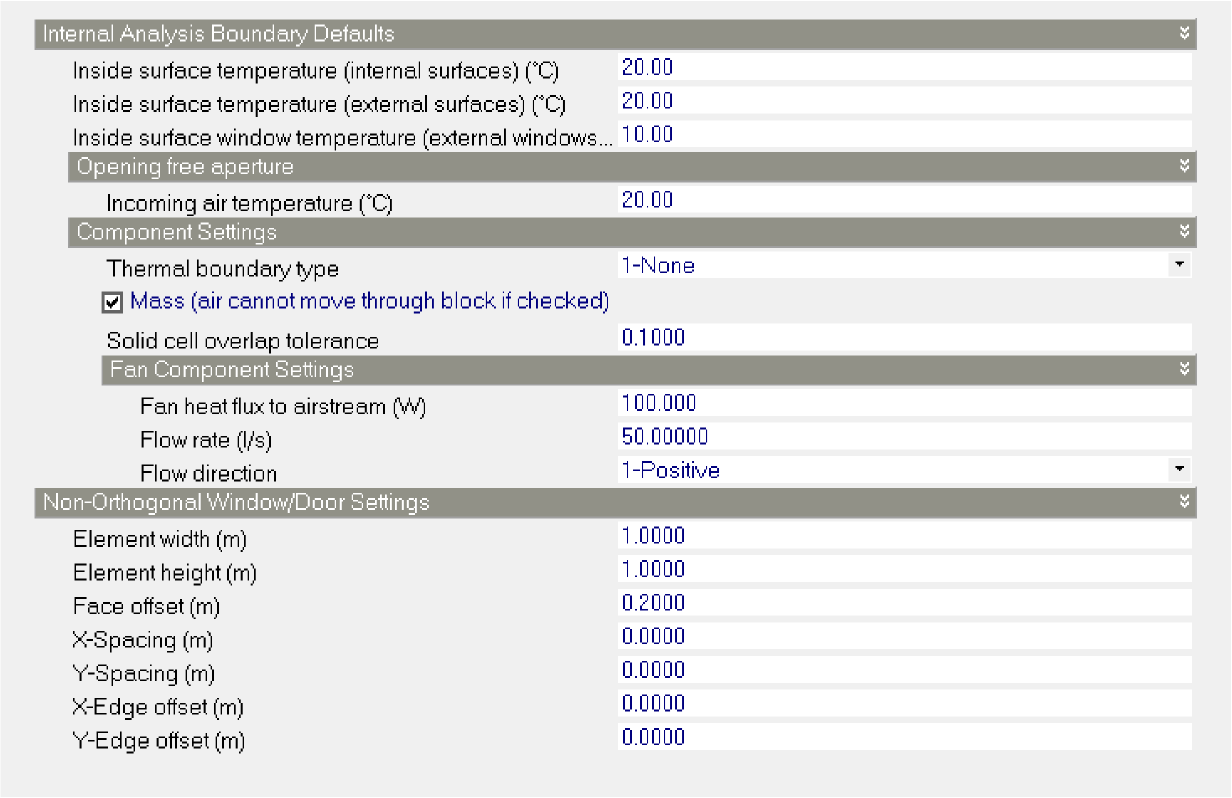
Summary Monthly Reports

Detailed Daylight Outputs

Miscellaneous Outputs

Daylighting Outputs

Working plane height (m): 0.750



Internal Analysis Boundary Defaults

Inside surface temperature (internal surfaces) (°C)	20.00
Inside surface temperature (external surfaces) (°C)	20.00
Inside surface window temperature (external windows...	10.00

Opening free aperture

Incoming air temperature (°C)	20.00

Component Settings

Thermal boundary type	1-None

☑ Mass (air cannot move through block if checked)

Solid cell overlap tolerance	0.1000

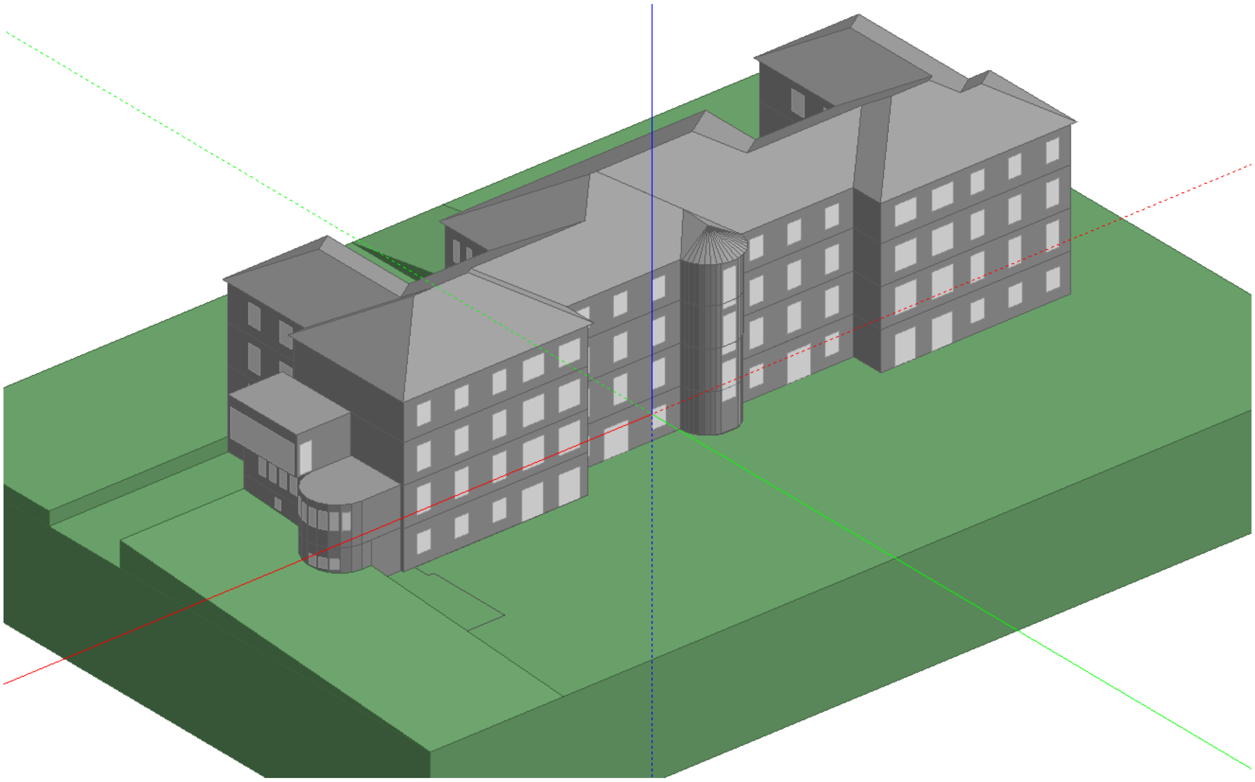
Fan Component Settings

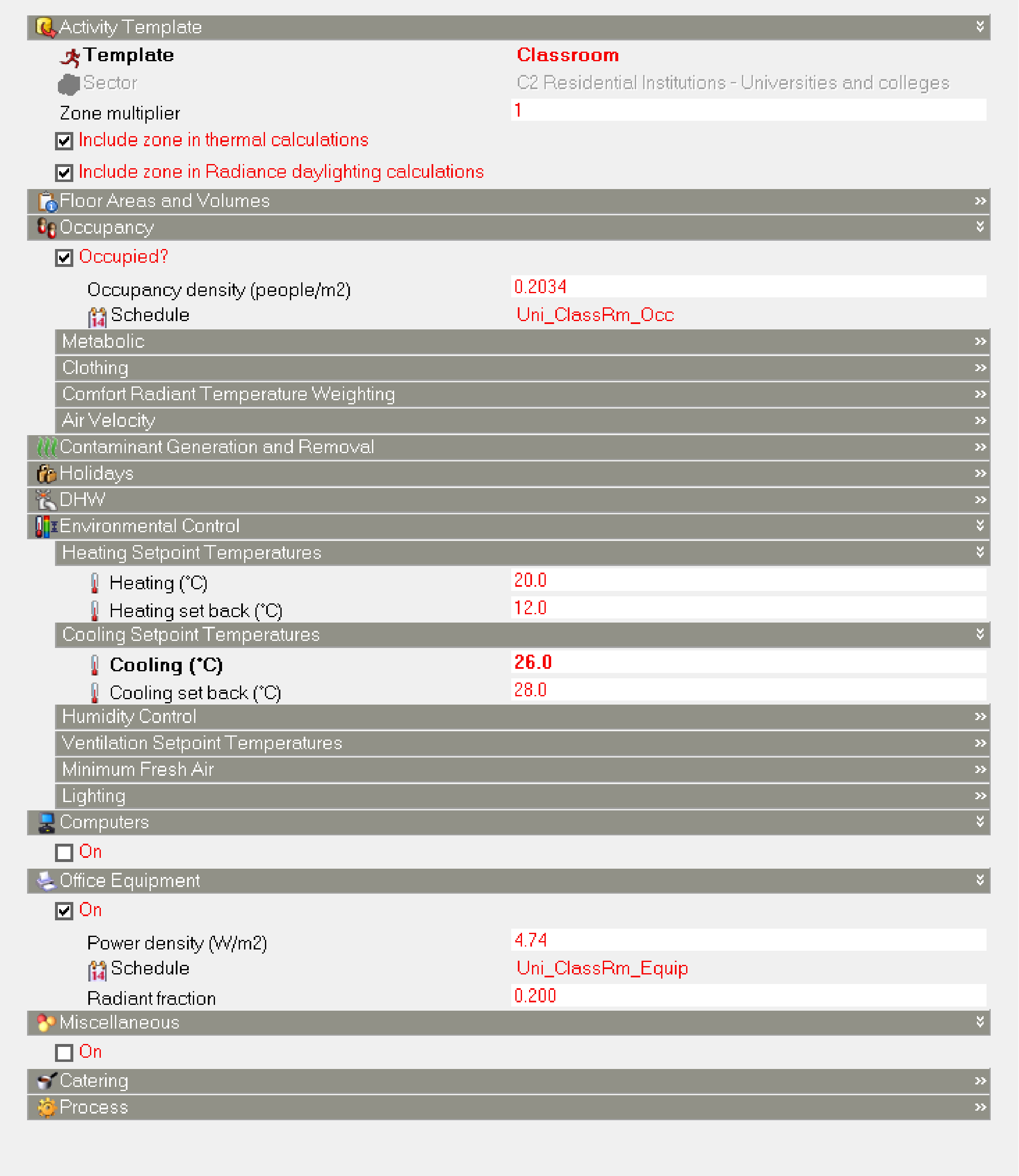
Fan heat flux to airstream (W)	100.000
Flow rate (l/s)	50.00000
Flow direction	1-Positive

Non-Orthogonal Window/Door Settings

Element width (m)	1.0000
Element height (m)	1.0000
Face offset (m)	0.2000
X-Spacing (m)	0.0000
Y-Spacing (m)	0.0000
X-Edge offset (m)	0.0000
Y-Edge offset (m)	0.0000

Lecco Building 12





Activity Template

Template **Classroom**

Sector C2 Residential Institutions - Universities and colleges

Zone multiplier 1

☑ Include zone in thermal calculations

☑ Include zone in Radiance daylighting calculations

Floor Areas and Volumes

Occupancy

☑ Occupied?

Occupancy density (people/m2) 0.2034

Schedule Uni_ClassRm_Occ

Metabolic

Clothing

Comfort Radiant Temperature Weighting

Air Velocity

Contaminant Generation and Removal

Holidays

DHW

Environmental Control

Heating Setpoint Temperatures

Heating (°C) 20.0

Heating set back (°C) 12.0

Cooling Setpoint Temperatures

Cooling (°C) **26.0**

Cooling set back (°C) 28.0

Humidity Control

Ventilation Setpoint Temperatures

Minimum Fresh Air

Lighting

Computers

☐ On

Office Equipment

☑ On

Power density (W/m2) 4.74

Schedule Uni_ClassRm_Equip

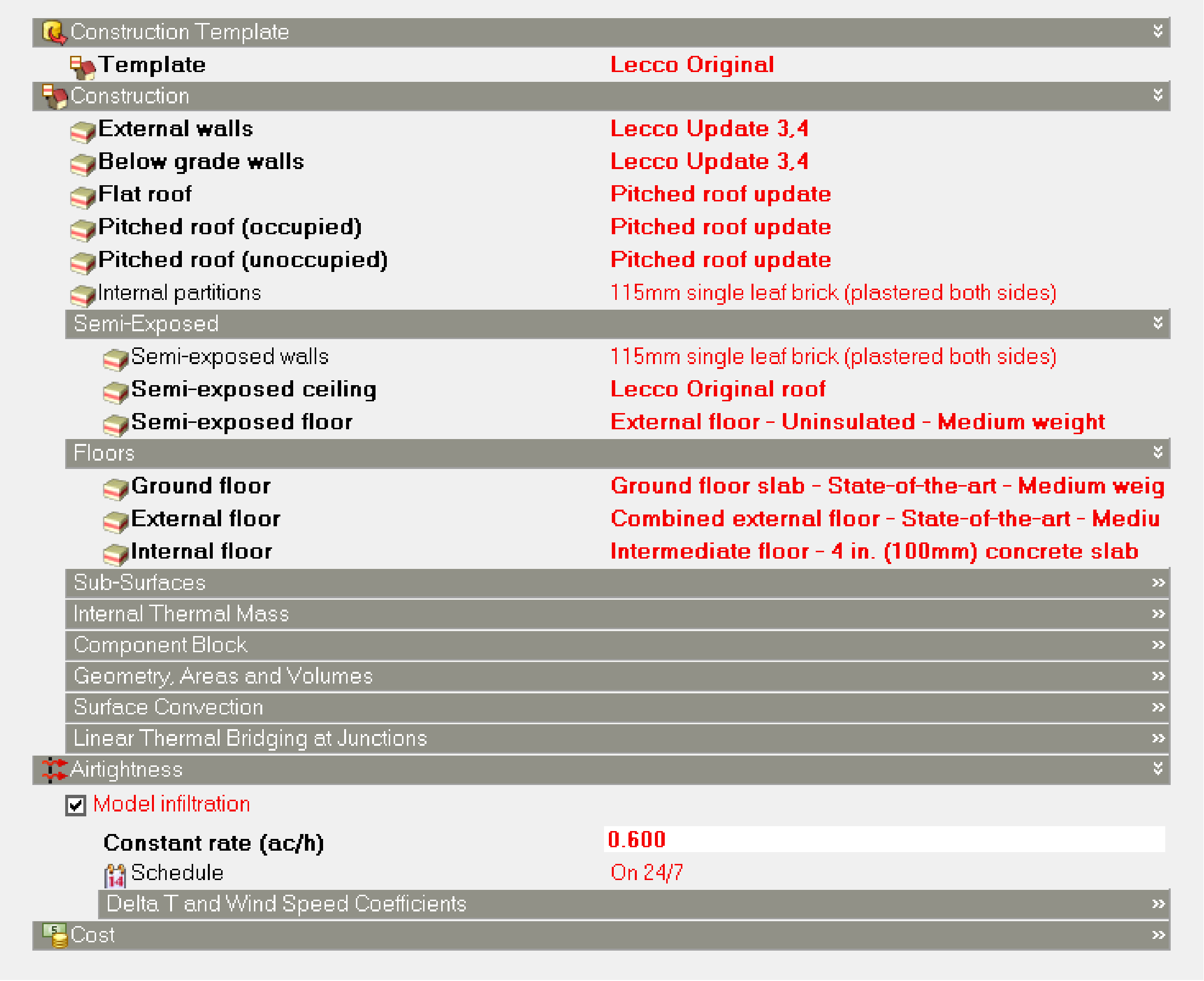
Radiant fraction 0.200

Miscellaneous

☐ On

Catering

Process



Construction Template

Template	**Lecco Original**

Construction

External walls	**Lecco Update 3,4**
Below grade walls	**Lecco Update 3,4**
Flat roof	**Pitched roof update**
Pitched roof (occupied)	**Pitched roof update**
Pitched roof (unoccupied)	**Pitched roof update**
Internal partitions	115mm single leaf brick (plastered both sides)

Semi-Exposed

Semi-exposed walls	115mm single leaf brick (plastered both sides)
Semi-exposed ceiling	**Lecco Original roof**
Semi-exposed floor	**External floor - Uninsulated - Medium weight**

Floors

Ground floor	**Ground floor slab - State-of-the-art - Medium weig**
External floor	**Combined external floor - State-of-the-art - Mediu**
Internal floor	**Intermediate floor - 4 in. (100mm) concrete slab**

Sub-Surfaces

Internal Thermal Mass

Component Block

Geometry, Areas and Volumes

Surface Convection

Linear Thermal Bridging at Junctions

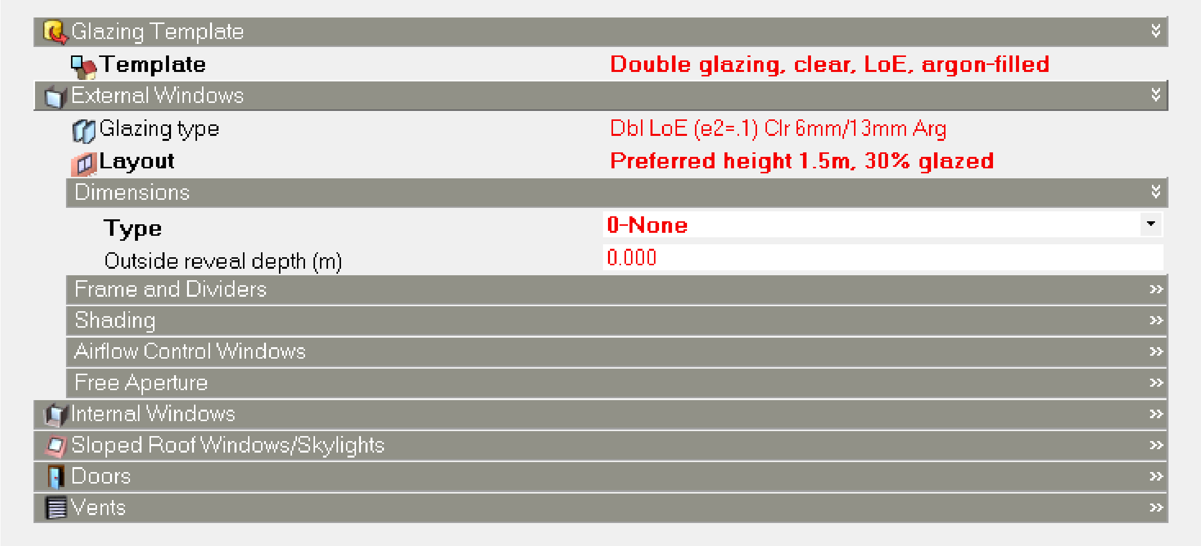
Airtightness

☑ Model infiltration

Constant rate (ac/h)	**0.600**
Schedule	On 24/7

Delta T and Wind Speed Coefficients

Cost



Glazing Template

Template	**Double glazing, clear, LoE, argon-filled**

External Windows

Glazing type	Dbl LoE (e2=.1) Clr 6mm/13mm Arg
Layout	**Preferred height 1.5m, 30% glazed**

Dimensions

Type	**0-None**
Outside reveal depth (m)	0.000

Frame and Dividers

Shading

Airflow Control Windows

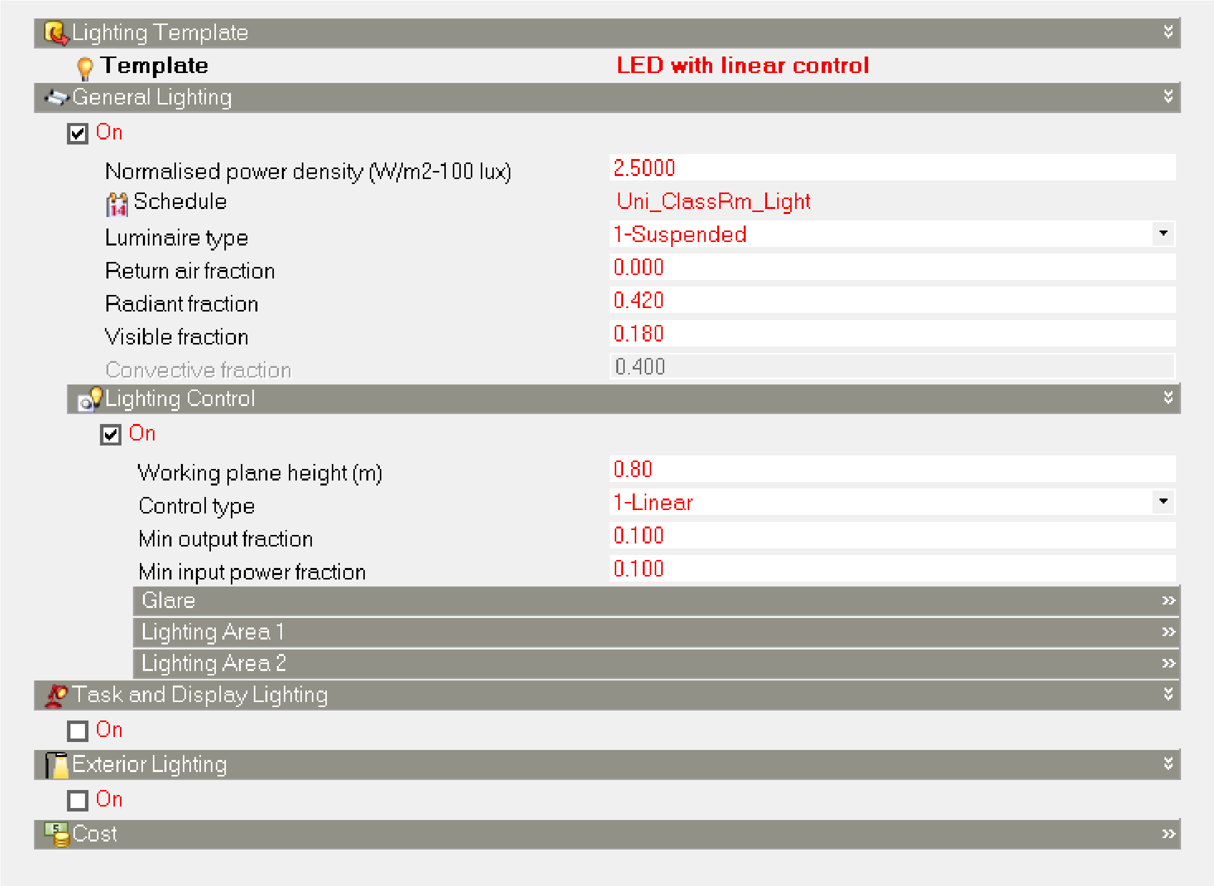
Free Aperture

Internal Windows

Sloped Roof Windows/Skylights

Doors

Vents



Lighting Template

Template LED with linear control

General Lighting

☑ On

Normalised power density (W/m2-100 lux)	2.5000
Schedule	Uni_ClassRm_Light
Luminaire type	1-Suspended
Return air fraction	0.000
Radiant fraction	0.420
Visible fraction	0.180
Convective fraction	0.400

Lighting Control

☑ On

Working plane height (m)	0.80
Control type	1-Linear
Min output fraction	0.100
Min input power fraction	0.100

Glare

Lighting Area 1

Lighting Area 2

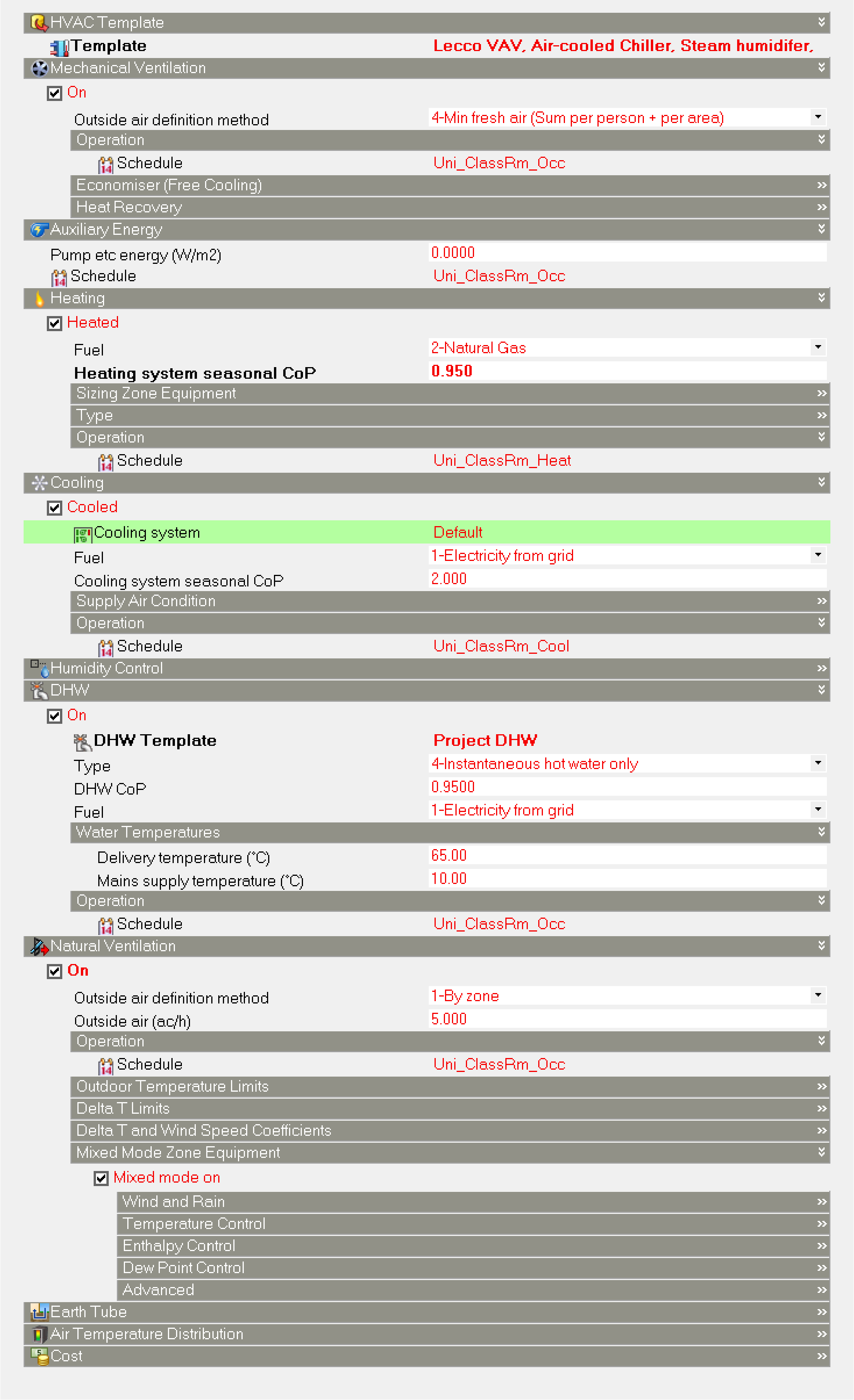
Task and Display Lighting

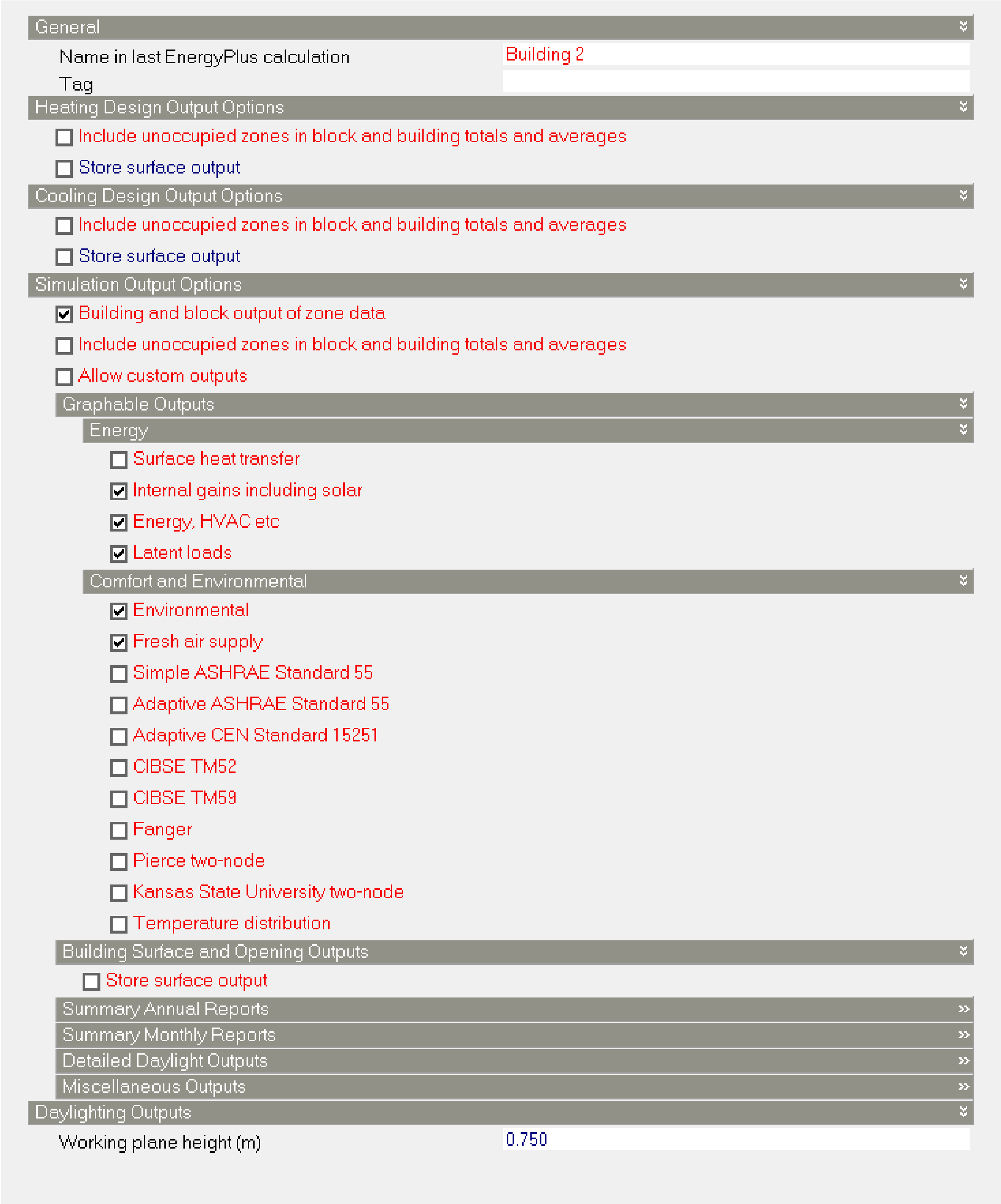
☐ On

Exterior Lighting

☐ On

Cost





General

Name in last EnergyPlus calculation: Building 2

Tag:

Heating Design Output Options

☐ Include unoccupied zones in block and building totals and averages

☐ Store surface output

Cooling Design Output Options

☐ Include unoccupied zones in block and building totals and averages

☐ Store surface output

Simulation Output Options

☑ Building and block output of zone data

☐ Include unoccupied zones in block and building totals and averages

☐ Allow custom outputs

Graphable Outputs

Energy

☐ Surface heat transfer

☑ Internal gains including solar

☑ Energy, HVAC etc

☑ Latent loads

Comfort and Environmental

☑ Environmental

☑ Fresh air supply

☐ Simple ASHRAE Standard 55

☐ Adaptive ASHRAE Standard 55

☐ Adaptive CEN Standard 15251

☐ CIBSE TM52

☐ CIBSE TM59

☐ Fanger

☐ Pierce two-node

☐ Kansas State University two-node

☐ Temperature distribution

Building Surface and Opening Outputs

☐ Store surface output

Summary Annual Reports

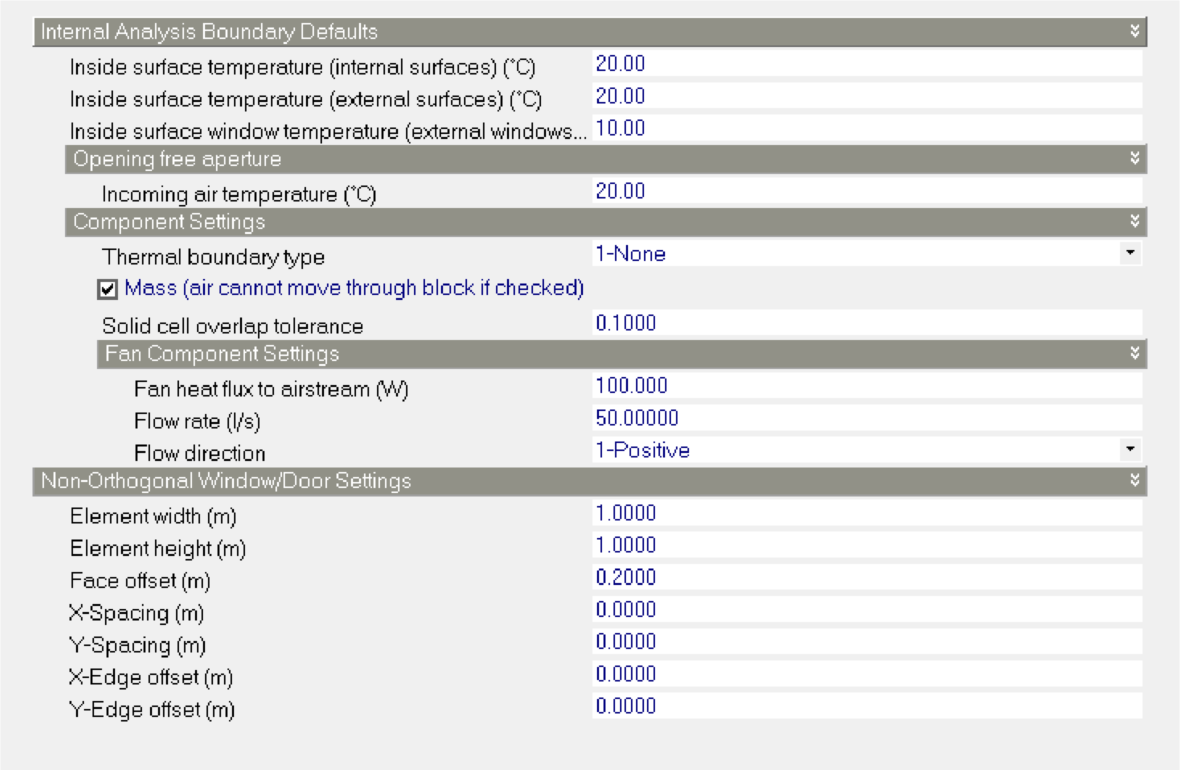
Summary Monthly Reports

Detailed Daylight Outputs

Miscellaneous Outputs

Daylighting Outputs

Working plane height (m): 0.750



Internal Analysis Boundary Defaults

Inside surface temperature (internal surfaces) (°C)	20.00
Inside surface temperature (external surfaces) (°C)	20.00
Inside surface window temperature (external windows...	10.00

Opening free aperture

Incoming air temperature (°C)	20.00

Component Settings

Thermal boundary type	1-None

☑ Mass (air cannot move through block if checked)

Solid cell overlap tolerance	0.1000

Fan Component Settings

Fan heat flux to airstream (W)	100.000
Flow rate (l/s)	50.00000
Flow direction	1-Positive

Non-Orthogonal Window/Door Settings

Element width (m)	1.0000
Element height (m)	1.0000
Face offset (m)	0.2000
X-Spacing (m)	0.0000
Y-Spacing (m)	0.0000
X-Edge offset (m)	0.0000
Y-Edge offset (m)	0.0000