Politecnico di Torino

Master Thesis

“From a Traditional Workplace to a Sustainable Smart Office”

In Collaboration with BIM and Energy Analysis software

Case study: Polytechnic University of Turin

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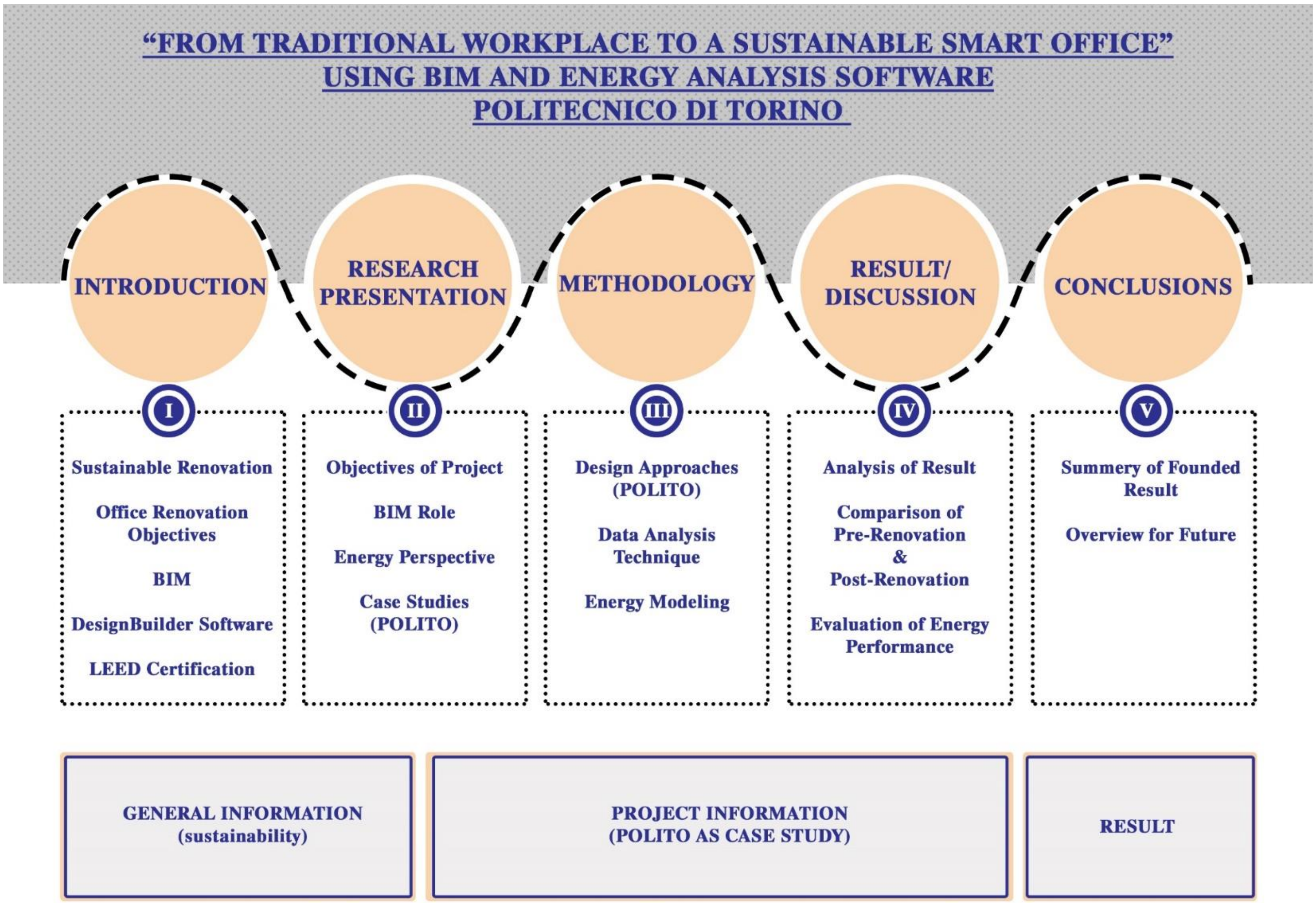


Fig 0.1 Thesis road map

1. Introduction

Building sustainability has grown in importance in recent years as a result of the negative environmental effects of construction activities and the substantial energy requirements of structures. Buildings account for over 40% of worldwide energy usage and greenhouse gas emissions, thus there is an increasing need to promote sustainable construction techniques that may lessen buildings' negative environmental effects while simultaneously enhancing their energy efficiency and interior environmental quality.

Renovation of existing structures offers a huge potential to enhance the environmental efficiency of buildings while also supplying inhabitants with a more pleasant and healthier indoor environment is one way sustainability may be encouraged. Given their high energy use and significant occupancy rates, office buildings in particular are a top target for rehabilitation.

With an emphasis on the use of Building Information Modeling (BIM) and DesignBuilder analysis, this thesis seeks to study the application of sustainable ways in office building rehabilitation. While DesignBuilder is a building performance simulation program that can be used to evaluate the energy performance of buildings and find potential for energy savings, BIM is a digital technology that enables collaborative building design and construction.

The goal of the thesis is to explore sustainable design techniques that can increase the building's energy efficiency while also improving the interior environmental quality for its inhabitants. It will study the application of BIM and DesignBuilder analysis to the refurbishment of an existing office building. In order to guarantee that sustainable design principles are applied throughout the project's lifetime, the research will also explore the communication and cooperation components of the refurbishment process.

This thesis demonstrates how BIM and DesignBuilder analysis can be used to create high-performance buildings that are environmentally sustainable, energy-efficient, and provide a healthy indoor environment for occupants. Overall, it aims to contribute to the development of sustainable renovation practices for office buildings.

1.1 Background and rationale for sustainable renovation

A sizable amount of the world's energy consumption and greenhouse gas emissions are caused by buildings. Buildings account for 30% of worldwide carbon dioxide emissions and almost 40% of global energy use, according to the International Energy Agency. Therefore, there is an increasing need to support sustainable construction techniques that may lessen buildings' negative effects on the environment while simultaneously enhancing their energy effectiveness and indoor environmental quality.

Existing building renovations offer a considerable potential to enhance environmental efficiency while also giving residents a cozy and healthy interior environment. In order to construct high-performance buildings that are ecologically friendly, energy-efficient, and provide a healthy interior environment for inhabitants, sustainable renovation entails integrating sustainable design ideas and practices into the rehabilitation process.

The importance of sustainable remodeling may be attributed to a number of factors. First off, it can lessen the negative effects that buildings have on the environment. Sustainable renovation can help lower greenhouse gas emissions and save natural resources by increasing the energy efficiency of buildings. Additionally, this may aid in reducing the consequences of climate change and encouraging a more sustainable future.

Second, environmentally friendly remodeling can help raise the interior air quality of buildings. Residents in poor-quality indoor environments may experience respiratory issues, allergy symptoms, and asthma. By enhancing ventilation, lowering indoor pollutants, and encouraging natural daylighting, sustainable remodeling can assist in solving these problems.

Thirdly, environmentally friendly remodeling has monetary advantages. Enhancing a building's energy efficiency can result in large energy bill savings and possibly even an increase in the building's value. Additionally, environmentally friendly refurbishment may boost the building industry's economy by generating jobs.

The promotion of a built environment that is more robust and sustainable can also help with sustainable renovation. Buildings may be constructed to be more adaptive, resilient, and better equipped to withstand the effects of climate change by incorporating sustainable design concepts into the refurbishment process.

Sustainable renovation is a crucial method for advancing environmental sustainability, enhancing indoor environmental quality, generating income, and fostering a built environment that is more robust and sustainable.

1.2 Objectives and significance of office renovation

OBJECTIVE:

1. To investigate the application of eco-friendly methods in the renovation of an existing office building.

2. To find environmentally friendly design approaches that can increase a building's energy efficiency while also improving the comfort of its residents.

3. study how Building Information Modeling (BIM) and DesignBuilder analyses are used during the renovation process and investigate how well they work to promote sustainable design.

4. To evaluate the components of the renovation procedure that involve cooperation and communication, to find strategies to encourage stakeholder participation, and to make sure that sustainable design principles are applied throughout the project's lifespan.

SIGNIFICANCE:

1. By demonstrating how sustainable design principles and practices can be incorporated into the renovation process to create high-performance buildings that are environmentally sustainable, energy-efficient, and provide a healthy indoor environment for occupants, the study will help develop sustainable renovation practices for office buildings.

2. In addition to emphasizing the value of stakeholder involvement and communication in advancing sustainable design practices, the research will offer advice on how to successfully guarantee that sustainable design principles are used throughout the course of a project.

3. The usefulness of these technologies in supporting sustainable design will be examined, along with the usage of BIM and DesignBuilder analysis in the renovation process. This will shed light on the possible advantages and restrictions of these technologies in the context of environmentally friendly restoration.

4. The study will add to the expanding body of knowledge on sustainable construction techniques and offer insightful information on how to use sustainable design principles in the context of office renovation.

1.3 Corona virus effects on workplace's space

In the long duration of the COVID-19 pandemic, since its outbreak, the pandemic has provided varied office working experiences that have given a greater understanding of workplace vulnerabilities against disease transmission. COVID-19 has affected the working style of professionals, irrespective of whether they worked from home or in commercial office spaces. In some industrial operations, where working from home was not possible, business owners and facility managers had to make arrangements and implement engineering and administrative measures to ensure the safety of on-site work. Workplace layouts were adjusted to provide some distance between neighboring workstations and ventilation systems were improved. Administrative instructions were issued to employees to maintain distancing requirements from other colleagues while at the office. All these measures acted as collaborative protective layers against the spread of COVID-19 to make office buildings and workplaces coherent working places once again [1]

1.3.1 Pre-Covid, Post-Covid

Break with the past During the government-imposed lockdowns, companies inevitably adapted to continue working assuring that main operations were done remotely, however, companies replicated what was done before the pandemic, by translating existing processes into remote working contexts. While in the past organizations were simply theorizing about new forms of work, the crisis of COVID-19 has forced them into taking actions, such as actually shifting to completely new ways of working, and even re-imagining new forms of work as required by the new pandemic circumstances. Therefore, companies must identify the most important processes within their organization, geography and functional structure, for their further re-evaluation involving both of management and employees. This effort should re-imagine the existing career development paths proposed by Human Resources – such as promoting intrapersonal relationships with closest co-workers by requiring face-to-face office contact at the beginning while gradually shifting toward remote work – and the execution of different business activity processes or production stages, such as limiting face-to-face meetings for planning activities while working remotely for the actual execution. The use of automation will be one of the change opportunities for the workplace of the future. Jobs should be redefined according to the desired workplace considerations, such as performance or productivity, that will determine the level and type of automation, where the use of Artificial Intelligence and semi-automation of repetitive and non-skilled work is the current reality. [2]

The negative side of the work from home concept: Following is a list of disadvantages of work from home concept:

1. Since one working from home, one can get disengaged from associates and bosses.
2. Working from home may cause numerous interruptions. One needs to go and attend to visitor, cook for family, clean home and oversee children.
3. Work from home makes an employee detached from his/ her company and make an employee lack the community feeling and attachment to his / her company.
4. It needs self-motivation commitment and devotion and being proactive, agile and resilient on behalf of the employees otherwise leading to un-productivity. Here HR plays a pivotal role to bring forth the concept of "People -connect".
5. WFH creates differences in culture with employees who work at office.
6. WFH does not foster communication and kinship with company.
7. Due to lack of psychological association with one's company, there is low reliability and retention of employees.
8. It is difficult to manage and maintain accountability of employees working from home. It leads to significant loss of productivity and motivation. [3]

Redesign the workplace to support organizational priorities We all have ideas about what a typical office looks and feels like: a mixture of private offices and cubicles, with meeting rooms, pantries, and shared amenities. Few offices have been intentionally designed to support specific organizational priorities. Although offices have changed in some ways during the past decade, they may need to be entirely rethought and transformed for a post– COVID-19 world. Organizations could create workspaces specifically designed to support the kinds of interactions that cannot happen remotely. If the primary purpose of an organization's space is to accommodate specific moments of collaboration rather than individual work, for example, should 80 percent of the office be devoted to collaboration rooms? Should organizations ask all employees who work in cubicles, and rarely have to attend group meetings, to work from homes? If office space is needed only for those who cannot do so, are working spaces close to where employees live a better solution? In the office of the future, technology will play a central role in enabling employees to return to office buildings and to work safely before a vaccine becomes widely available. Organizations will need to manage which employees can come to the office, when they can enter and take their places, how often the office is cleaned, whether the airflow is sufficient, and if they are remaining sufficiently far apart as they move through the space. To maintain productivity, collaboration, and learning and to preserve the corporate culture, the boundaries between being physically in the office and out of the office must collapse. In-office videoconferencing can no longer involve a group of people staring at one another around a table while others watch from a screen on the side, without being able to participate effectively. Always-on videoconferencing, seamless in-person and remote collaboration spaces (such as virtual whiteboards), and asynchronous collaboration and working models will quickly shift from futuristic ideas to standard practice. [4]

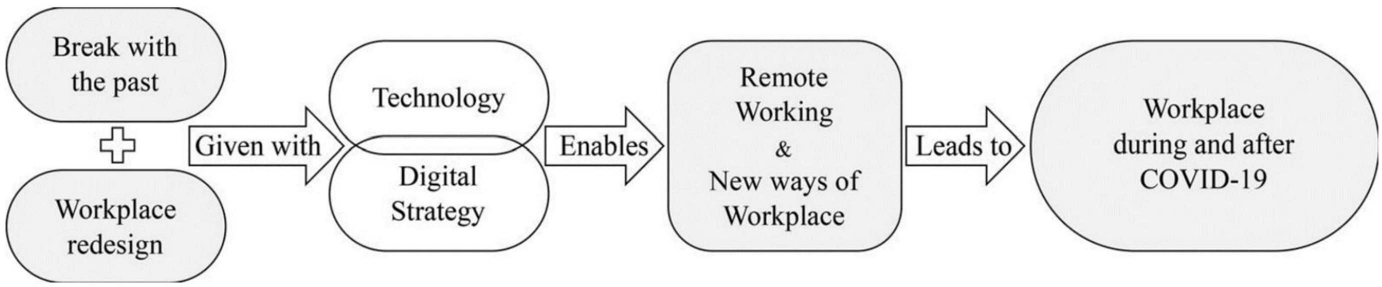


Fig 1.1 Redesigning notion through new Covid-19 designing

What is new: Now more than ever it is necessary to understand the factors and processes that make it possible for a workplace to be transformed from a dehumanized place into a nice place to work, that can give meaning to people's work and turn around society (Michaelson et al., 2014) and, as part of companies' policies, can improve talent management practices (Younas & Bari, 2020). The truth is that COVID-19 has taken everyone by surprise and the situation has changed radically since March 2020, leading to a serious rethinking of what the workplace currently is, and what it will be during and after COVID-19 (World Economic Forum, 2020b, 2020a). Certainly, it seems that nothing will remain the same, and this paper tries to provide the lines that lead to this new workplace that was impossible to imagine a few months ago (McKinsey, 2020b). [5]

1.3.2 Workplace ecosystem scenarios

The New Workplace Ecosystem: Typology of Space Figure 3 presents an elaborated typology of space for the new workplace ecosystem in the context of global industry concepts and industry metrics available on the market. Considering global projections of 'work [from] anywhere' (IPUT/ARUP, Cushman and Wakefield, CBRE, and Deloitte), it can be observed that understandings of workplace environments vary across the industry. For example, recent 'post-COVID-19 workplace ecosystem' definitions, emphasising the importance of the wider urban environment and a mix of spaces (urban realm, third places, and home), is not fully addressed by workplace design and management monitoring tools evaluated in this paper. Still, there is a strong focus on the traditional office building as the dominant physical space where work occurs. Although the internal office environment remains a core focus of all workplace tools, some of them (e.g., WELL and BREEAM) recognize outdoor environmental quality albeit limited to nearby office surroundings (the crossovers between LEED and BREEAM environmental certifications and the WELL Community Standard were not included in this study). Also, some industry leaders (e.g., Leesman)—in the pandemic context—have recently gained interest in the home environment and its evaluation. And while Thrive Global does not aim to evaluate workplace design and management, its tool could potentially be adapted to monitoring employee health and well-being in the office, third places, and home. Still, the factors assessing physical home environments may need further investigation as they are often limited to standard office workplace designs (e.g., availability of desk, chair, etc.). Additionally, the recent shift to remote work highlights the importance of virtual workplace quality and related digital infrastructure (WiredScore) for both office and home environments. That is, this trend can potentially enhance and support remote work tendencies within the wider urban realm (e.g., third places), requiring the adaptation of new digital tools like those offered by Thrive Global to measure organizational factors (e.g., employee engagement metrics) for different places of work.[6]

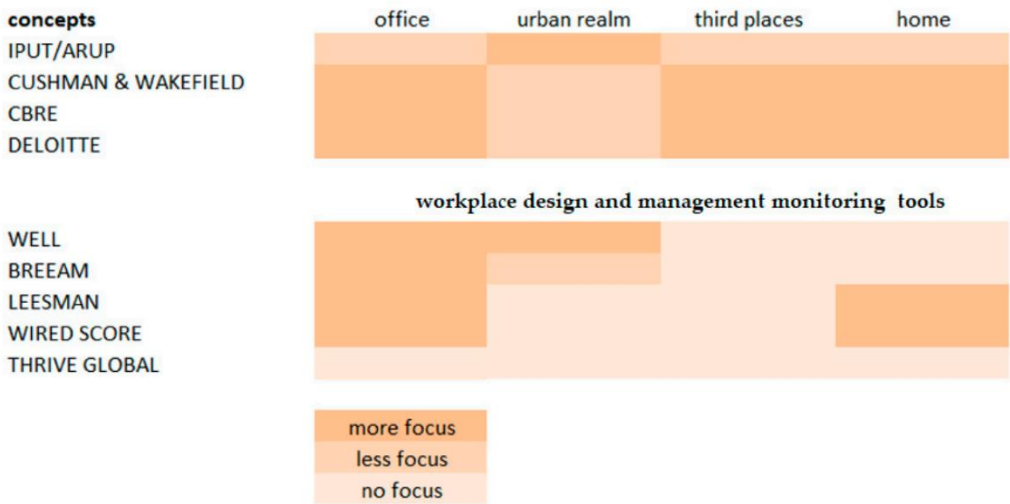


Fig 1.2 New workplace eco-system/ typology of spaces

1.4 physical workplace environment impact employee engagement

Desirable work environment comprises both physical and emotionally safe environment that will motivate the employee to be engaged at work. Studies (Holbeche and Springett, 2003), show that people perceive their workplace, and their contribution in their role at workplace, play a major part in their engagement and hence performance. The study also argues that employees actively seek meaning through their work and, unless organizations try to provide a sense of meaning, employees are likely to leave. Work environment is expected to create a shared sense of destiny with others and to encourage employees to emotionally connect with one another to achieve high levels of engagement. Therefore it is evident that employees personal perception of their working environment shapes and directs how engaged an employee is. To have a positive perception, it is important to have a supportive working environment.

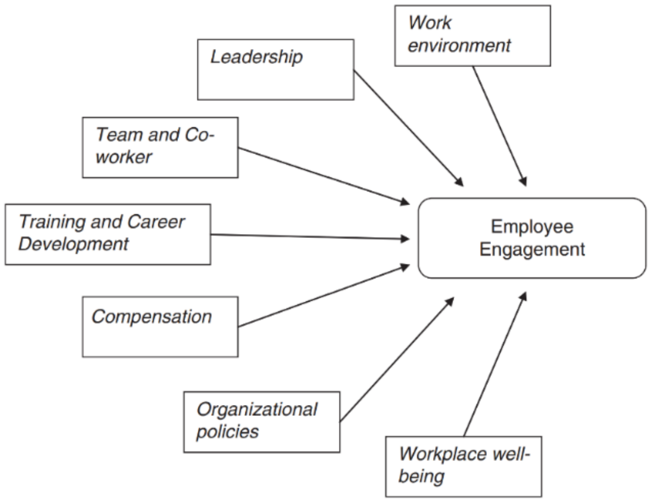


Fig 1.3 Employee engagement

Studies (Islam and Shazali, 2011) show that a good quality physical working environment leads to better service to customers and supports higher output. These studies also reveal that the working environment should comprise a good culture, working with a good team, a good boss, good physical surroundings, job security, sustainable compensation package, and availability of food and drink in the workplace. The presence of all these factors in the workplace could increase the morale of workers and contribute to increased manufacturing productivity. Therefore organizations and employers should concentrate on improving the working environment of the employees in different ways. This should include appreciating the employees' efforts, communicating the success and accomplishment of the organisation to the employees thereby inculcating ownership among employees, provide them with a balance between work and personal life, provide required information and resources for effective output and provide a safe environment. Hence it is the responsibility of management to offer a workplace that ensures the above.

Similarly the factor team and co-worker relationship is also significantly influential on employee engagement. Collegial and professional skills play an important role in the success of fresh employees (Hertzog et al., 2000). The result explains that higher order needs, such as achievement and collaborative decision making, that reflects team and co-worker relationship, leads employees to take on greater responsibility to achieve shared goals and visions. Studies (Kahn, 1990) also suggest that client relations for some individuals, such as camp counsellors, may play a role in providing a meaningful work experience.[7]

1.5 BIM (Building Information Modeling)

Building Information Modeling (BIM) is a digital modeling technology used in the architecture, engineering, and construction (AEC) industry. BIM allows construction professionals to create virtual models of buildings and infrastructure projects, which can be used for design, construction, and maintenance purposes.

In the context of a thesis project, BIM can be used in a variety of ways. Here are a few examples:

1- Creating a 3D model of a building: BIM can be used to create a highly detailed, three-dimensional model of a building. This model can include information about the building's physical characteristics, such as its dimensions, materials, and structural components.

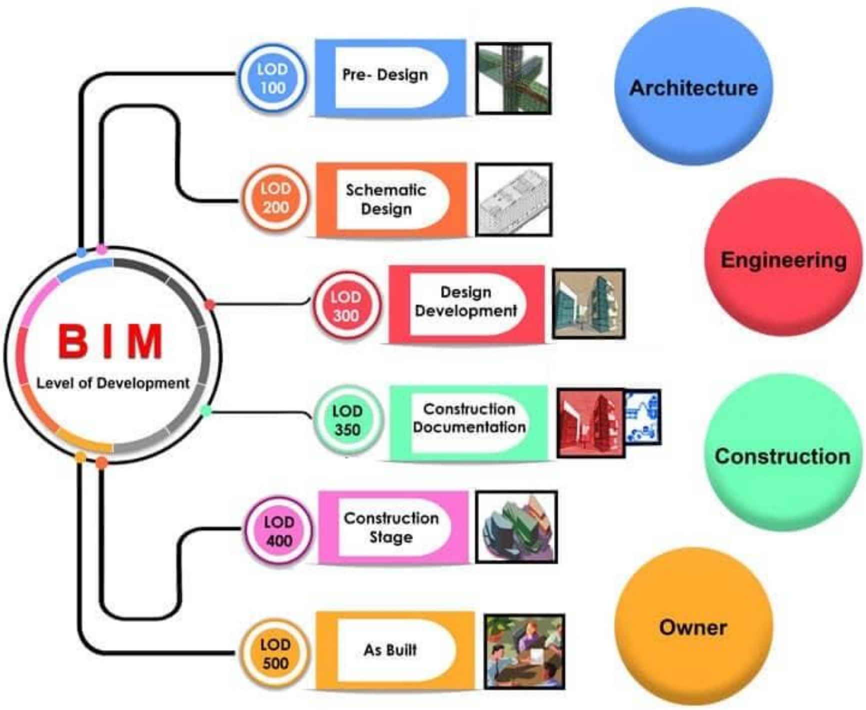
2- Analyzing the performance of a building: BIM can be used to simulate the performance of a building under different conditions, such as different weather patterns or occupant loads. This allows researchers to analyze how the building will perform in the real world and identify potential issues before construction begins.

3- Optimizing the design of a building: BIM can be used to optimize the design of a building by simulating different design scenarios and analyzing their impact on the building's performance. For example, researchers can use BIM to determine the most energy-efficient orientation for a building or to optimize the placement of windows to maximize natural light.

4- Creating construction drawings and documents: BIM can be used to create detailed construction drawings and documents, which can be used by contractors and construction teams during the building process.

LoD is a theoretical concept to support model development. The idea is that you attach a LoD status attribute to objects in conjunction with standardized reusable checklists. Thus you can, with increased certainty, guarantee a certain quality of information at a given point [13]. The concept of LoD was pioneered by Vico and Weber [27] in 2005 together with a model progression specification (MPS) and possible application. After this, many versions of the concept, with add-ons, emerged around the world [7,13]. The latest and known for being one of the most important is the Information Model Protocol Form with basic LoD-definitions and standardized Responsibility Matrix [13]. The other important one is the Level of Development Specification that attempts to clarify what the designers may mean about the different building elements [3]. The Danish company MTHøygaard displays examples of what the different levels can typically have of information [23]. LoD differs between geometry and properties. A model can be well developed through geometry without having much information concerning the properties of the model. In such a case, the model has a low level of properties and high level of geometry [3]. The different versions around the world are dividing the levels in different ways. BIMForum [3] uses these definitions (here summarized): x LoD100: Approximately information, often generic representation. Seldom geometry. x LoD200: Approximately geometry as a system or element with size, form and location. x LoD300: Element represented as a specific system or object with size, form, location and amount. x LoD350: As 300, including interface with other building elements. Example: Assembly plate between columns and foundation x LoD400: The element is modelled sufficient to exact production as bases for fabrication. x LoD500: The element gives an exact picture of the real element. As built.[8]

Fig 1.4 Tree of BIM – Level of Development



1.5.1 Sustainability and BIM

Building Information Modeling (BIM) and sustainable renovation are two important areas in the construction industry. BIM is a digital modeling technology that is used to create virtual models of buildings and infrastructure projects, while sustainable renovation refers to the process of renovating buildings in a way that reduces their environmental impact and improves their energy efficiency.

Developing sustainable Solutions requires an expansion of traditional thinking it is necessary to include more input parameters and consider a longer period of time while making decisions during the design process. Often as designers, are asked by peers, clients or other professionals to break down the process for sustainable design into simple steps that are easier to follow. this is our order of operation and it is derived from the following common methodology for reducing the energy consumption of buildings.

1- Understanding climate
2- Reducing loads
3- Using free energy
4- Using efficient systems

We have extended on the thinking behind the energy consumption methodology and through our work have developed the following order of operations which you can take advantage of through the design process.

1- Understanding climate, culture and place
2- Understanding the building type
3- Reducing the resource consumption need
4- Using free/local resources and natural system
5- Applying renewable energy
6- Offsetting remaining negative impacts

To combine sustainability with BIM, it is important to consider we can recognize the options upper in the analysis with BIM software such as Autodesk REVIT. BIM can understand:

- Building orientation
- Building massing
- Daylighting
- Water harvesting
- Energy modeling
- Renewable energy
- Materials [9]

Which this information are very important to us for analyse the building in order to have best solution for sustainable ideas.

1.5.2 Effectiveness and benefits of using BIM in the renovation process

Combining BIM and sustainable renovation in a thesis project can be a powerful way to explore the potential benefits of using BIM technology to support sustainable renovation practices. Here are a few ideas on how this could be approached:

1- Use BIM to model and simulate the renovation process: BIM technology can be used to create 3D models of existing buildings and simulate different renovation scenarios. By incorporating sustainable design principles into these simulations, researchers can explore how different renovation strategies can impact the environmental performance of a building.

2- Analyze the environmental impact of different renovation strategies: BIM can be used to perform life cycle assessments of different renovation strategies, allowing researchers to compare the environmental impact of different approaches. For example, researchers could analyze the energy consumption of a building before and after a renovation project, and assess the environmental benefits of different types of energy-efficient systems and materials.

3- Develop guidelines for using BIM in sustainable renovation: Based on the findings of the thesis project, the researcher could develop guidelines for using BIM to support sustainable renovation practices. These guidelines could be used by architects, engineers, and contractors to ensure that sustainable design principles are incorporated into renovation projects from the outset.

1.6 Energy Analyzer software

Architects, engineers, and construction experts may use DesignBuilder, a complete building simulation software program, to create and improve high-performance buildings. Energy modeling, daylighting analysis, HVAC design, and thermal performance analysis are just a few of the many features and functionalities offered by the app.

The ability to represent energy is one of DesignBuilder's core features. Users of the program may design complex 3D models of structures that include the building exterior, interior design, and HVAC systems. The software may run energy simulations using this model to ascertain the building's energy efficiency under various circumstances.

Additionally, DesignBuilder includes daylighting analysis tools that enable users to maximize natural light and reduce energy usage by optimizing the location and size of windows, skylights, and other building components. The program can carry out complex calculations to estimate how much natural light will reach a structure at various times of day and in various climates.

The HVAC design abilities of DesignBuilder are another important aspect. Air handling units, chillers, boilers, and other HVAC systems are among those included in the app. Users can create and improve HVAC systems to achieve certain performance objectives, such as lowering energy usage or enhancing occupant comfort.

The thermal performance of building components, such as walls, roofs, and floors, may also be examined by users thanks to the thermal performance analysis tools included in DesignBuilder. To assist users in maximizing the building's energy efficiency and thermal comfort, the software calculates heat transfer coefficients, U-values, and other significant thermal attributes.

Overall, DesignBuilder is potent building simulation software that gives users a full range of tools for developing and improving high-performance structures. Whether you're an architect, engineer, or construction expert, DesignBuilder can assist you in making sustainable, comfortable, and energy-efficient structures.

1.6.1 Energy analysis software and its role in sustainable design and renovation

Energy analysis software is critical to sustainable design and renovation because it allows architects, engineers, and building experts to assess and optimize building energy efficiency. This program delivers useful insights about a building's energy usage, efficiency, and renewable energy integration possibilities. Some significant characteristics of energy analysis software and its function in sustainable design and refurbishment are as follows:

- Energy analysis software enables designers to evaluate a building's energy performance by assessing elements such as heating, cooling, lighting, ventilation, and overall energy use. Designers may compare and analyze numerous design possibilities to determine the best energy-efficient solutions by modeling different situations.

- Energy modeling techniques are used in these software programs to simulate and anticipate a building's energy use based on parameters such as insulation, HVAC systems, orientation, and occupancy patterns. They may create thorough statistics on energy use, demand, and expenses, which can assist designers in understanding the influence of various design choices on energy efficiency.

-Renewable Energy Integration: Energy analysis software identifies potential for incorporating renewable energy sources into building design, such as solar panels, wind turbines, or geothermal systems. It may assess the feasibility, output, and cost-effectiveness of various renewable energy systems, allowing for more informed decision-making for long-term energy integration.

- Daylighting and Natural Ventilation: Energy analysis software can evaluate a building's potential for daylighting and natural ventilation. It assesses elements including window location, shading devices, and natural airflow patterns, allowing designers to optimize natural light and ventilation and decrease dependency on artificial lighting and mechanical systems.

-Life Cycle Analysis: Sustainable design and refurbishment need to take into account a building's complete life cycle. Energy analysis software can assess the environmental effects of various materials, construction methods, and operating strategies during the life cycle of a structure. This approach aids in the identification of possibilities to reduce embodied energy, carbon emissions, and resource use.

-Compliance with Local Building Codes and Energy Standards: Many energy analysis software programs are intended to comply with local building codes and energy standards. Designers may use these tools to guarantee that their projects fulfill the essential energy efficiency standards and regulatory norms, assisting them in obtaining the appropriate certifications and licenses.

-Cost Analysis: Cost analysis software can estimate the initial investment, operational expenses, and possible energy savings associated with various design options. This data assists project stakeholders in making educated judgments about the long-term financial feasibility of sustainable design and restoration initiatives.

1.6.2 LEED certification

Leadership in Energy and Environmental Design (LEED) is a green building certification program used worldwide.[3] Developed by the non-profit U.S. Green Building Council (USGBC), it includes a set of rating systems for the design, construction, operation, and maintenance of green buildings, homes, and neighborhoods, which aims to help building owners and operators be environmentally responsible and use resources efficiently.

By 2015, there were over 80,000 LEED-certified buildings and over 100,000 LEED-accredited professionals. Most LEED-certified buildings are located in major U.S. metropolises. LEED Canada has developed a separate rating system adapted to the Canadian climate and regulations. Some U.S. federal agencies, state and local governments require or reward LEED certification. This can include tax credits, zoning allowances, reduced fees, and expedited permitting. Studies have found that for-rent LEED office spaces generally have higher rents and occupancy rates and lower capitalization rates.

LEED is a design tool rather than a performance-measurement tool and focuses on energy modeling rather than actual energy consumption. It lacks climate specificity, and has been criticized for a point system that can encourage inappropriate design choices and make energy conservation the weakest part of the evaluation. It has also been criticized for the phenomenon of "LEED brain" in which the public relations value of LEED certification drives the development of buildings.

LEED 2009 encompasses ten rating systems for the design, construction and operation of buildings, homes and neighborhoods. Five overarching categories correspond to the specialties available under the LEED professional program. That suite consists of:

- Green building design and construction (BD+C) – for new construction, core and shell, schools, retail spaces (new constructions and major renovations), and healthcare facilities
- Green interior design and construction – for commercial and retail interiors
- Green building operations and maintenance
- Green neighborhood development
- Green home design and construction

To achieve LEED certification, a project earns points by adhering to prerequisites and credits that address carbon, energy, water, waste, transportation, materials, health and indoor environmental quality. Projects go through a verification and review process by GBCI and are awarded points that correspond to a level of LEED certification: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points) and Platinum (80+ points).[10]

Fig 1.5 LEED certification badge

2. Research Presentation

2.1 Steps and Objectives of Project

An existing office building can be renovated in a sustainable way to increase its sustainability and energy efficiency while preserving or even enhancing its usability. Given their potential to affect both the environmental performance of the building and the health and well-being of its occupants, construction materials are a crucial part of sustainable office renovation. Using building materials as the basis, here is a thorough description of sustainable workplace renovation.

1- Products with recycled material
Recycled materials are a great method of reducing the building's influence on the environment when renovating offices. To decrease the amount of trash produced during construction, materials like repurposed steel, plastic, and glass can be used in the building process. Materials with recycled substances can also aid in lowering the quantity of unprocessed materials required for the remodeling.

2- Low-VOC substances
Chemicals called volatile organic compounds (VOCs) can be released from some construction components and harm occupants' health. The interior air quality in offices can be improved, and the health hazards related to VOCs can be decreased by using low-VOC materials. Low-VOC paint, adhesives, and coatings are a few examples of low-VOC products.

3- Eco-friendly wood products
Although wood is a common resource for construction, not all wood is viable. By using wood products that have received certification from agencies like the Forest Stewardship Council (FSC), you can help guarantee that the wood originates from forests that have been sustainably managed. Utilizing salvaged wood from other sources or recycled wood from old structures can also lessen the need for new wood and contribute to trash reduction.

4- Energy-efficient insulation
As it has a significant impact on the building's energy efficiency, insulation is a crucial part of a sustainable workplace renovation. Utilizing energy-efficient insulation materials like repurposed denim, fiberglass, or cellulose may assist in reducing energy consumption as well as heating and ventilation expenses.

5- Energy-efficient windows
Window plays a significant role in the energy economy and comfort of the structure, making them an essential part of sustainable office renovation. Heat intake and loss can be minimized in the winter and summer by installing double-paned, low-E coated energy-efficient windows. A further way to enhance interior air quality and reduce the need for artificial cooling is to install windows that allow for natural ventilation.

6- Renewable energy sources
Renovating offices with sustainable energy systems like solar panels, wind turbines, or geothermal systems can help to lessen the building's dependence on fossil fuels and its emissions of greenhouse gases. Renewable energy sources can also provide a consistent supply of energy and help to gradually lower energy expenses.

7- Water-efficient fixtures
Putting in water-saving devices like low-flow toilets and taps can help reduce water usage and water costs. Utilizing materials that are moisture and microbial resistant can also help to enhance interior air quality and lower the possibility of water damage.

As a result, choosing a sustainable construction substance for a workplace renovation is a difficult process that calls for careful evaluation of a number of variables, including energy efficiency, indoor air quality, and environmental effect. Office renovation can help to lessen the building's effect on the environment, enhance the health and wellbeing of its inhabitants, and save money over time by utilizing sustainable building materials and energy-efficient systems.

2.1.1 Steps through the design

The requirements of the assignments and problems we must address should be taken into account at the outset of the design process. Based on research, an office renovation should be clever and account for every possible issue that should be noted. Finding the best choice for the designs and supplies requires consideration of a variety of options. These alternatives could be more useful when we can compare the strengths and weaknesses of each one.

At this point, one of two important options needs to be chosen for implementation. The first would be the design of the work environment and the design system that would be taken into consideration, and the second would be the best sustainable strategies that could be applied to lower energy usage and other sustainability-related factors.

2.1.2 Survey of different case studies

1- Bullitt Building, Seattle, The United State

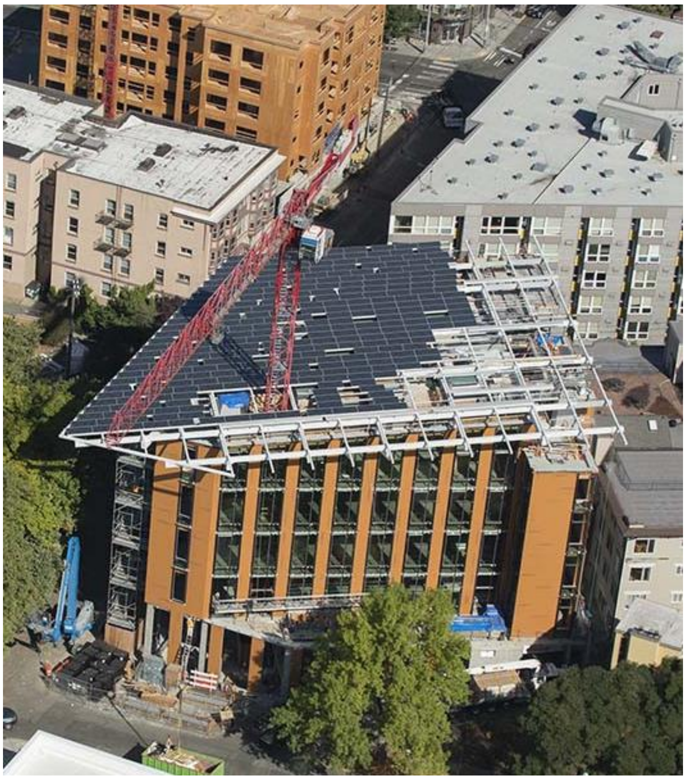
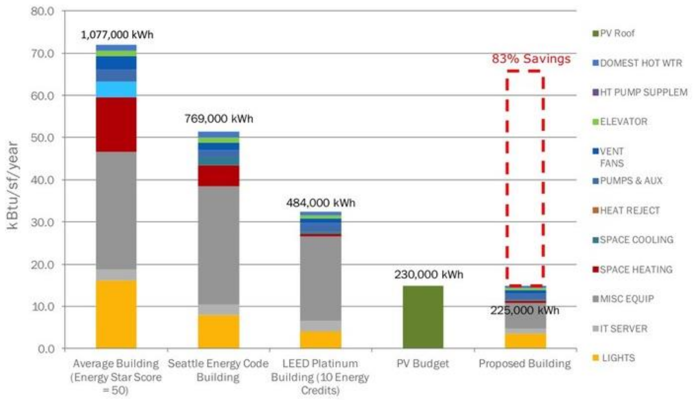


Fig 2.1 Fig 2.2 Bullitt building views

The building has exceeded expectations for thermal comfort and daylighting, as well as energy use during its first year of operation. Throughout the first year of operation the building was warm and draft-free in the winter, cool and comfortable in the summer, and beautifully daylit year around. Occupants of the building express a high level of satisfaction with the quality and comfort of the indoor environment.



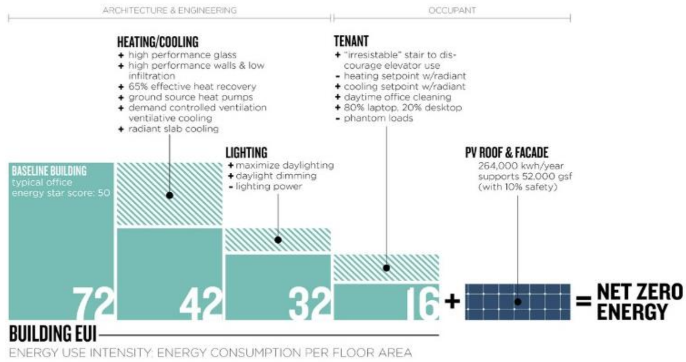


Fig 2.3 Energy use and Solar budget

Fig 2.4 The path to net zero energy

Occupancy accounts for part of the Bullitt Center's exceptional energy performance. On average the building was occupied at about half of its design occupancy during the first year. Since about half of the building's predicted energy use is from "activity loads" directly tied to the number of people using the building, the corrected target for the building's energy use is about 12.3 kBTU/sf year. At the Center for integrated Design we're working with the design team to understand how energy is used in this building to know why its performance is exceeding predictions. Whole building energy and power use, and energy production data, has been collected since the PV power production plant went on-line and began supplying the building with energy in early 2013. But while every circuit in the building has the capability of being monitored, validating end-use, circuit-by-circuit data has been elusive. Until we have reliable end-use data,

we can only speculate why the building is performing even better than anticipated.

Step 1: Set Aggressive Goals To achieve high performance there must be a commitment by everyone involved to high performance goals. Net-zero was the energy performance goal for the Bullitt Center. Further design and energy analysis following the design charrette resulted in a six story, 50,000 square feet, with space for a PV "power plant" that could supply the annual energy needs of a building with an EUI of 16 kBTU/ sf • year. This was the design team's energy target.

Step 2: Analyze the Site and Climate High performance design is about designing with nature. It begins by asking three questions: What is here? What will nature allow us to do here? And what will nature help us do here? This means considering conditions during all 8,760 hours in a year and includes understanding the day-to-night temperature swings, rainfall, cloud cover, and the hourly availability of sun, wind and light. Informed by this understanding, the design team established climate design priorities and architectural design strategies.

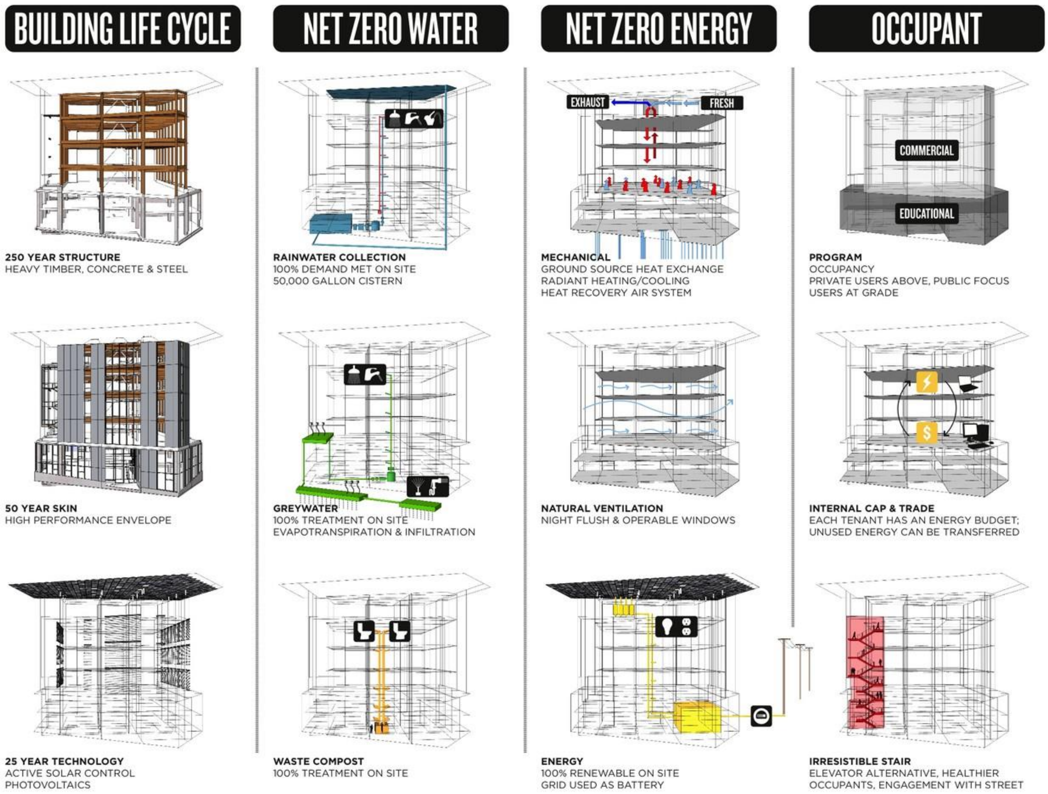


Fig 2.5 Graphical analysis of Bullitt building

Step 3: Design for Reduced Energy Demand The building's form, envelope, and organization was informed by the climate, use, and building systems, and rigorously tested, modeled and evaluated to optimize its performance. The objectives are a comfortable, healthy, beautiful building that can "sail" without the need for mechanical assistance as long and as often as possible. Reducing the energy demands of the building is half the challenge. The other half is to make it easy and natural for people who work here to use as little energy possible. An "irresistible stair" to reduce elevator use, showers and bike parking to promote human-powered transportation, and low-flow fixtures and composting toilets are just some of the ways "activity loads" are reduced or eliminated.

Step 4: Use Efficient Equipment The design team selected smart, energy efficient equipment and systems to deliver the remaining need for heating, cooling, ventilating and illumination. Sensors connected to the building's central nervous system monitor light levels, CO 2 levels, temperatures indoors and outdoors, as well as wind and sun, to control and deliver heating, cooling, ventilation and illumination efficiently and effectively. Step 5: Use Renewable Energy The sunlight that falls on the building, and the energy source or sink of the earth beneath it, are the only sources of sustainable, renewable energy used to operate this building and power the equipment inside. Step 6: Verify Performance Stewardship is a process of steady commitment informed by constant feedback. It requires careful maintenance and vigilance to the performance goals for the project. This building's vital signs will be monitored and its performance analyzed with the goal of continuous improvement in its operational use of energy.

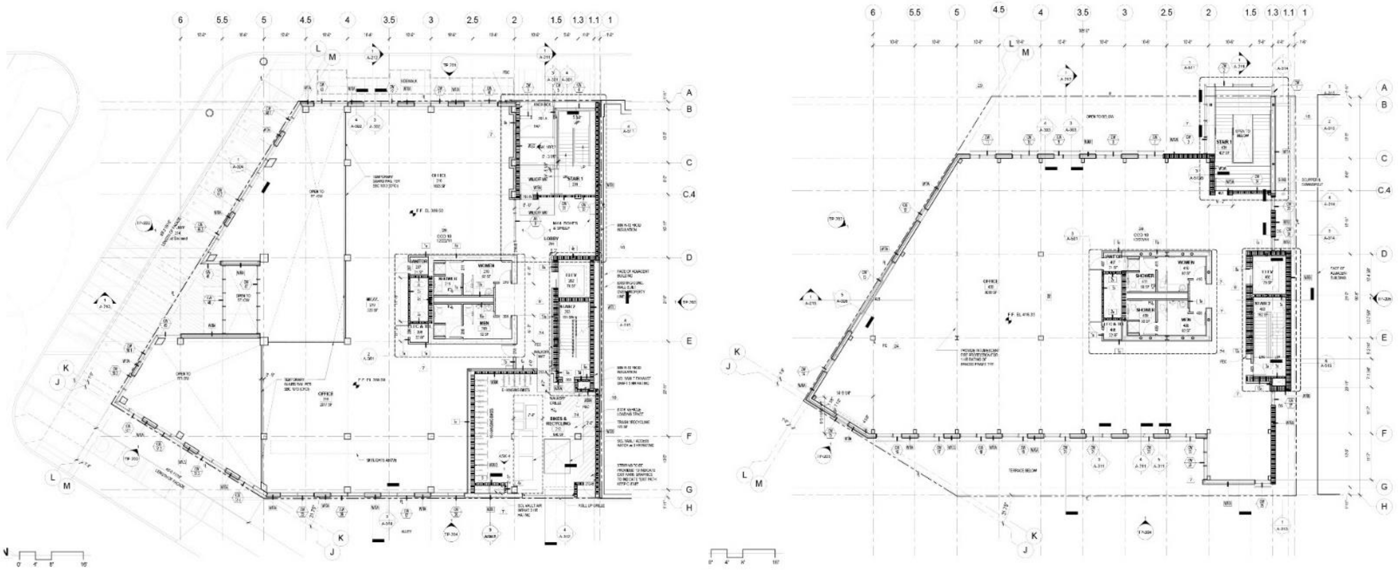


Fig 2.6 Bullitt building plans (Left: Ground Floor / Right: Tip Floors)

Sustainable strategies which influence in the designing process:

- Solar panels: The Bullitt Building's rooftop solar array is made up of 575 photovoltaic panels that can generate up to 230,000 kilowatt-hours of electricity per year. This is enough to power the entire building's electrical needs and helps reduce the building's reliance on grid-supplied electricity.
- Rainwater collection and treatment system: The building collects rainwater from the roof and stores it in a 56,000-gallon cistern. The water is then treated and used for the building's toilets and landscaping, reducing the building's reliance on potable water.
- Green roof: The building's green roof covers approximately 1/3 of the total roof area and is planted with a variety of native plants. The green roof helps absorb rainwater, reducing stormwater runoff and providing insulation to the building, which can help reduce heating and cooling costs.
- Radiant heating and cooling system: The Bullitt Building uses a radiant heating and cooling system, which circulates water through a network of pipes in the floors and ceilings. The system is more energy-efficient than traditional HVAC systems because it operates at lower temperatures and distributes heat more evenly throughout the building.
- Non-toxic building materials: The Bullitt Building was constructed using non-toxic building materials, such as FSC-certified wood, low-VOC paints and adhesives, and formaldehyde-free insulation. These materials are healthier for building occupants because they emit fewer harmful chemicals into the air.
- Operable windows: The building's windows can be opened to provide natural ventilation, reducing the need for mechanical cooling. The windows are also designed to minimize glare and heat gain, which can help reduce cooling costs.
- LED lighting: The Bullitt Building uses energy-efficient LED lighting throughout the building. LED lighting uses less electricity than traditional lighting and can last up to 25 times longer, reducing the need for frequent replacement.
- Water-efficient fixtures: The Bullitt Building uses water-efficient fixtures throughout, including low-flow toilets and faucets. These fixtures use less water than traditional fixtures, reducing the building's water consumption and associated costs.[11]

2- Pixel Offices, Melbourne, Australia

The brief for Pixel was to provide a 6 Star Greenstar Carbon Neutral home for the Development team and Sales offices, a display suite area and a green roof top viewing area, for the duration of the development's construction and sales phase. Behind this very functional program is the opportunity to enhance Grocon's Greenstar Credentials, and provide a cost effective and exemplary building that reflects the standards Grocon will demand in the remaining projects on the site. studio505 have designed a very simple and coherent office building, which is woven together from a series of integrated environmental systems. With Umow Lai, studio505 have sought to deliver the ultimate ESD rateable performance within a coherent architectural product, worthy of the design aspiration of the overall site.

Fig 2.7 Pixel building view (Façade)

Pixel radically pushed the boundaries of what is achievable in a Green Building. Many new sustainable building technologies were implemented, including a complex water capturing system, solar and wind harnessing, thermal cooling, water usage reduction through. Vacuum toilets, anaerobic digester to reduce waste from toilets and Pixelcrete, a specially designed concrete that contains half the embodied carbon of conventional concrete for the same structural properties.

A complex and colorful facade wraps the western and northern sides of the building, giving Pixel its iconic identity. A simple but intricate assembly of zero waste, recycled color panels providing maximized daylight, shade, views and glare control. Panels are supported by the Living Edge spandrels which create shading and grey water treatment as well as providing immediate personal greenery to every office floor. The facade wraps continuously around Pixel creating a vibrant and unique identity.

Furthering its green ambitions, Pixel's rooftop is clad with fixed and tracking photovoltaic panels, vertical wind turbines and an extensive green roof.

Fig 2.8 Roof heating system (Pixel building)

Pixel has been designed to capture, filter and process rain water via its green roof and water storage systems. This volume of water, based on Melbourne's annual average rainfall, would be sufficient for all the non-potable requirements of the building.

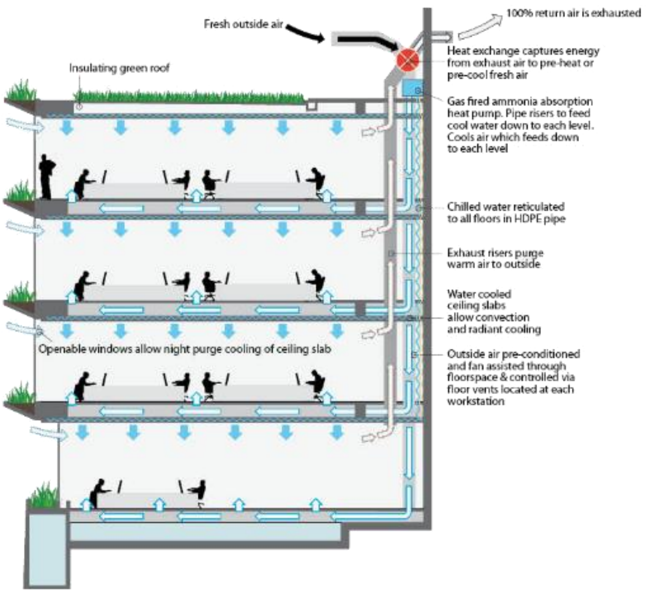


Fig 2.9 Pixel colling system

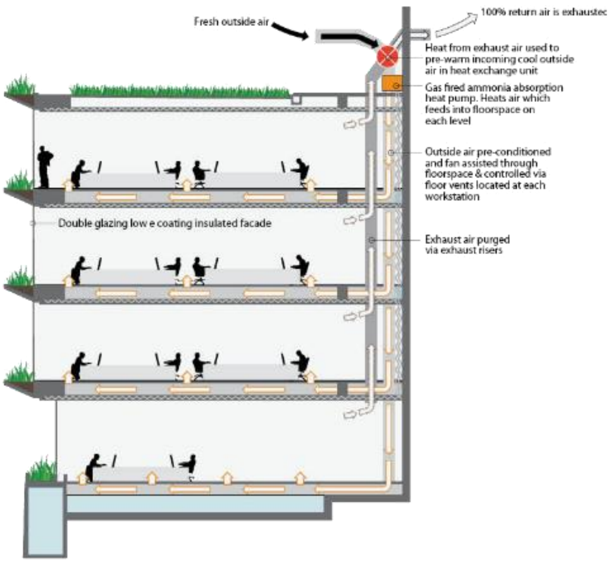


Fig 2.10 Pixel heating system

An innovative greywater system allows Pixel to utilize rain collection to meet the demands of the buildings non-potable water requirements. Rainwater is collected on the green roof, passes through a rainwater filtration and osmosis treatment plant and supplies the buildings vacuum toilets, basins and showers. Greywater from these units then passes through reed beds that provide passive greywater treatment.[12]

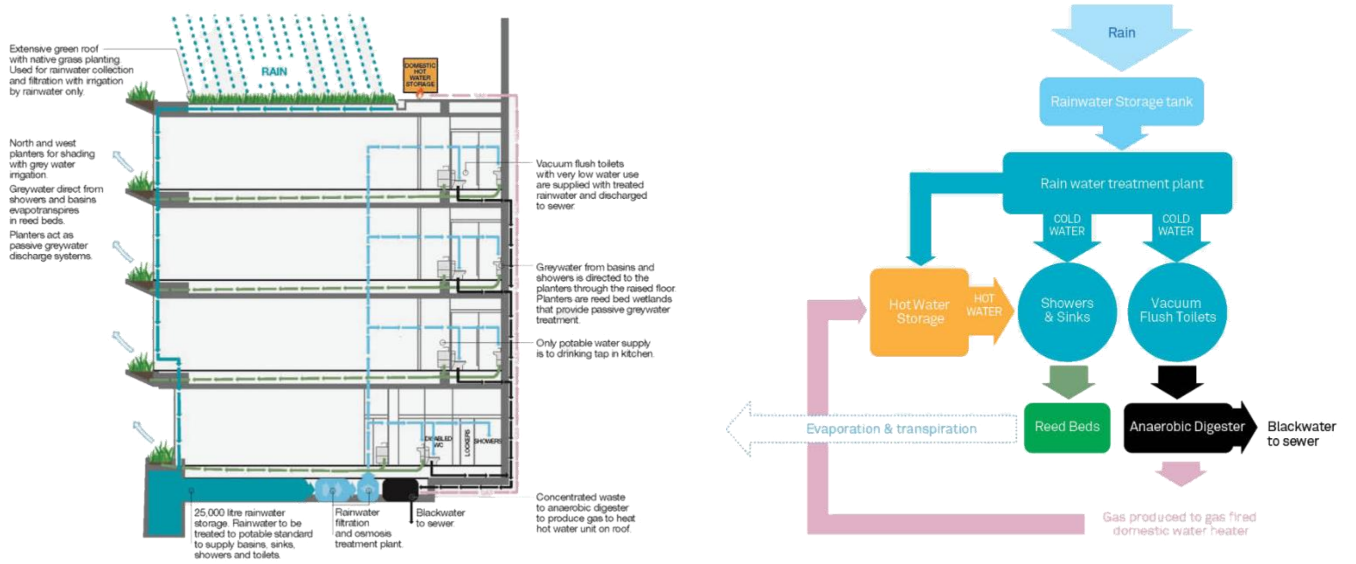


Fig 2.11 Pixel water cycle

2.1.3 Sustainable strategies

The use of sustainable wall solutions in office renovations can reduce your influence on the environment, enhance employee health and wellbeing, and produce a more aesthetically pleasing and eco-friendly workplace.

Below there are some suggestions for this purpose:

1- Consider using sustainable materials while remodeling the offices, such as recycled steel, repurposed wood, or sustainable bamboo for the wall coverings. These materials enhance the visual appeal of your workplace while also being environmentally responsible.

2- Use energy-efficient lighting: By utilizing LED lights and other energy-efficient lighting, you may minimize your energy usage and energy costs. In order to further reduce energy use, you may also install occupancy sensors that automatically switch off the lights when the room is not in use.

3- Install insulation: Insulating your walls will help the workplace use less energy by reducing heat gain and loss in the summer and winter. By doing this, you can cut your energy costs and carbon footprint.

4- Use low-VOC paint: Low-VOC (volatile organic compound) paints are better for the environment and human health when painting your walls. The air quality in your office is improved by these paints since they release fewer dangerous chemicals into the atmosphere.

5- Include greenery: Plants may help to clean the air and make an area seem more inviting and natural. A living wall installation or putting potted plants on your desks and shelves are both excellent ways to include plants in the office decor.

2.2 Role of BIM and Energy Analysis

Gholami et al. (2013) claim that BIM is mostly accepted and encouraged by specialists using different tools in the construction industry. For the renovation projects, designers and contractors should be able to recommend BIM as it reduces environmental degradation and increases energy efficiency. BIM is mostly used for visualization, collaboration, energy simulation and prototyping.[13]

Most of the time, parametric tools during the renovation process are reused for coordination, energy simulation and visualization. Based upon the capability of BIM, it provides extensive visualization and high quality rendering which are presented to stakeholders (Gholami et al., 2013). For this reason, stakeholders and clients with different levels of knowledge would have a better understanding of projects through these abilities, which are given by BIM. Effective use of BIM can be obtained if it is implemented from the initial stages of a project. However, it can be used during any stage such as maintenance, operation etc. Another advantage of BIM is to facilitate certificates for building environmental performance like BREEAM. Further, BIM saves time in the design phase compared to other options, and should be able to provide the optimal solution as well as the various simulations (energy simulation etc.).[13]

For Gholami et al. (2013) one of the potential advantages of BIM in renovation projects is to estimate the energy performance of alternatives by creating models. From several studies in literature, it is clear that energy simulation has a vital importance in determining the performance of renovation projects. In that sense, implementation of BIM and providing early energy simulation could increase efficiency of renovation processes.[13]

2.2.1 Benefits of using BIM in renovation projects

Lately, the expectations of tenants for buildings have become diverse and irregularities in the design of buildings have become wider (Park & Kim, 2013). Furthermore, in renovation projects, issues such as energy performance and sustainability become important to consider. In this context, current 2D models are not capable of handling complicated design and managing large, complex construction projects and 12 information flow throughout the whole process of the project. In addition to this, in order to avoid data conflicts and unnecessary works, there must be an appropriate management system.[13]

Responding to current problems in renovation projects, many studies are conducted in the area of information and communication technologies. From this research, BIM emerges as a new ICT to solve problems and increase productivity also in renovation. One of the main benefits of BIM is to create an effective early collaboration between project participants. Furthermore, early involvement of contractors in the design phase makes it possible to take more straight decisions on cost estimation and arranging the construction materials. However, there are restrictions due to data transfers between different software tools and legal contract issues (Park & Kim, 2013).[13]

All of the interviews were started with the main features of BIM usage in renovation projects. Regarding the question, type of the renovation projects was specified in the beginning as large renovation projects to interviewees instead of small sized. Furthermore, main features of BIM usage depend on the project type as all the interviewees stated in the beginning. Mainly, they are not using BIM for smaller sized 18 renovation projects. According to three interviewees, the main features of BIM usage are geometry and logistics in renovation projects.[13]

- Geometrical feature As to the geometrical feature of BIM, the obvious method is to use 3D Laser Scanning to get a proper and better picture of the building by coordinating 3D geometrical aspects. Interviewee A pointed out the importance of 3D Laser Scanning in order to get the materials that they are going to use for the renovation project and this action allowed them to keep their budget in the right track. In addition to this, using 3D Laser Scanning regarding BIM gave the exact measurements of the components of the buildings which provided them with lots of advantages in their work. On the other hand, when the drawings are pretty old for renovation projects, 3D Laser Scanning helps them to see the changes, improvements and modifications that were made in the past which are not specified in the old drawings. For Interviewee D, the geometrical feature of BIM was not clear as they do not commonly use BIM in all projects but according to him 3D Laser Scanning would be really efficient in the design phase in some projects.[13]

- Logistics feature with regard to the logistical feature of BIM, the interviewees believe that BIM gives good visualization, high quality of input data and helps the logistic companies to deliver and put the materials into construction site properly. However, Interviewee D agreed upon the logistical feature as pointed out the design of the construction site is easier with this feature however they do not use this feature of BIM in renovation projects so often. 4.2.3 Database feature The database feature of BIM is more commonly used for waste management than energy, HVAC or material quality. According to Interviewee A, they have an agreement with the waste companies that have a section on waste types in BIM, which help them to handle all kinds of waste properly. For the database of waste, Interviewee D was not sure if it is connected to BIM database or not. 19 4.2.4 Main stages of BIM use in renovation projects Generally, BIM usage in renovation projects does not cover all the stages of the project according to interviewees. From the responses, recently the design phase has become the most common stage of BIM usage in renovation projects. For Interviewee C, BIM is used for clash control in the production phase in addition to the design phase.[13]

2.2.2 Smart offices elements (Sustainable behavior)

Design for Sustainable Behaviour (DfSB) is an evolving field of design research and practice which sits within the broader context of sustainable design (Wever, 2012; Bhamra and Lilley, 2015). It is concerned with the application of behavioural theory to understand users, and behaviour changing strategies to design products, services and systems that encourage more sustainable use. Since its conception in the mid-2000s (Rodriguez and Boks, 2005; Lilley et al., 2006) a small yet dedicated community of scholars have contributed to the advancement of theories, strategies and design processes for DfSB. However, although there is a lively degree of debate concerning the nuances within DfSB, actively encouraged given the relative immaturity of the field, there is an emerging consensus on what constitutes a DfSB design process. The DfSB design process typically follows a sequence of five phases:

- The forming of an understanding of the user's actions in context;
- The informed selection of a behavioural target;
- The selection of a single or multiple corresponding behavioural intervention strategy(ies);
- The production of appropriate behavioural intervention design solutions;
- And, the evaluating of the behavioural intervention against the specified target behaviour.[14]

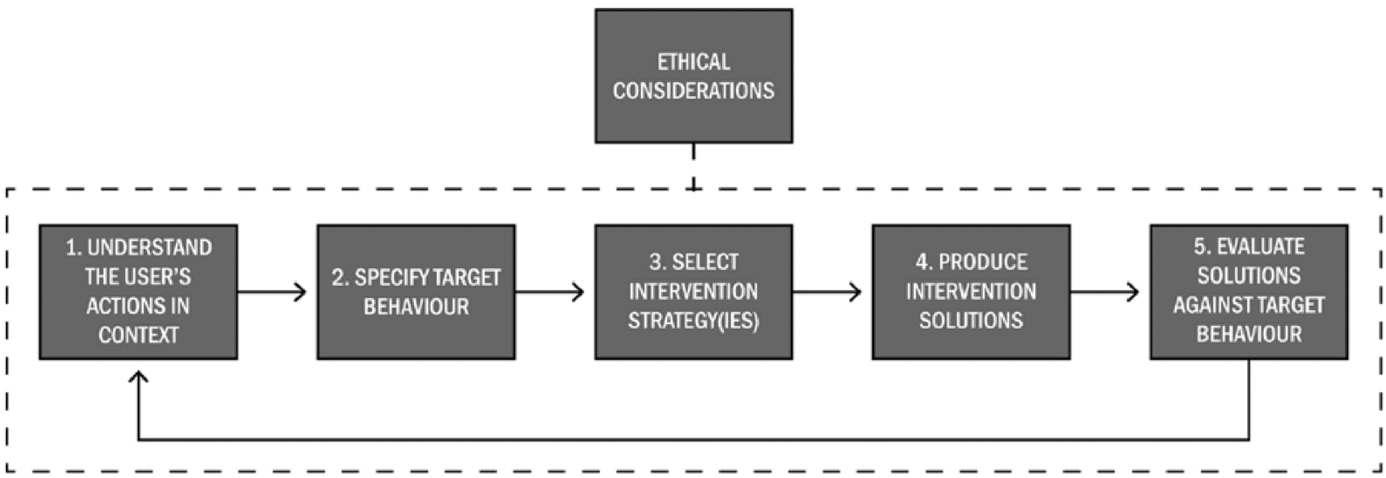


Fig 2.12 Design for Sustainable Behaviour phases

As depicted in Figure 1, though not explicitly a phase in its own right, consideration should be given, throughout the design process, to potential ethical issues which may arise in relation to data collection, the selection of target behaviours and strategies and the resulting behaviour created through the intervention designed (Lilley and Wilson, 2013).[14]

Smart office apps can reduce the time employees normally spend on administrative tasks, freeing them up to focus on their core responsibilities or the parts of the job they enjoy most. The smart office concept states that numerous pieces of software exist that can make collaboration easier, such as Zoom or Slack, resulting in a more productive team dynamic and enabling hybrid or remote working. Additionally, sensors and software can be installed to track what resources staff use most, which can lead to reduced operational costs.

10 Must-Have Smart Office Features:

- Collaboration Tools
- Smart HVAC
- Smart Office Accessories
- Smart Workplace Apps
- IoT Security Solutions
- Smart Technologies to Prevent COVID-19
- Proactive Maintenance of Different Systems
- Use of AI for Administrative Task
- Flexible Workplace
- Smart Energy Usage

2.3 Case study POLITO Building

Politecnico di Torino's main campus, often known as the Polytechnic University of Turin, is an iconic and prominent university in Turin, Italy. The building of the university's main campus was critical in creating the university's character and providing a favorable atmosphere for study, research, and cooperation. Here's an overview of the main campus of Politecnico di Torino's construction:

The main campus is located in the center of Turin, a city noted for its rich cultural legacy and economic power. Since its inception in 1859, the institution has developed to become one of Italy's major technological universities. The site has undergone various extensions and modifications throughout the years to suit the institution's expanding demands and incorporate new architectural trends.

Turin, the capital city of the Piedmont region in northwest Italy, is geographically advantageous. Turin is set in the middle of the gorgeous Susa Valley, surrounded by the majestic Italian Alps, on the banks of the Po River. The city has a continental climate, with scorching summers and freezing winters and fog that imparts a mysterious appeal to the scene. Turin's strategic position has also contributed to its historical and cultural importance, as it has served as a crossroads for commerce, industry, and cultural exchanges for millennia. Turin is now a lively city that combines natural beauty, a rich history, and modern urban development.

Fig 2.13 Turin Province location in Italy

Fig 2.14 Map of Metropolitan city of Turin

Architectural Design: The main campus of Politecnico di Torino features a combination of traditional and contemporary characteristics. The campus is made up of structures that exhibit numerous architectural styles from various eras. This fusion of old and contemporary architecture represents the university's dedication to both innovation and legacy. The main campus is distinguished by buildings with majestic façades, elaborate detailing, and vast courtyards. The design ideas emphasize facilitating contact and multidisciplinary cooperation among students, professors, and researchers by establishing a harmonic blend of academic spaces, research facilities, and social places.

Sustainable characteristics: The main campus has a variety of ecologically friendly characteristics in keeping with Politecnico di Torino's dedication to sustainability. Natural lighting, ventilation, and energy efficiency are all optimized in the structures. To lessen the campus's ecological imprint, sustainable materials and building practices are used.

Fig 2.15 Main campus of Politecnico di Torino

Furthermore, the campus encourages sustainable mobility by offering bicycle racks, pedestrian-friendly walkways, and easy access to public transportation. These activities are in line with the university's emphasis on sustainability and environmental responsibility.

In the following, we address the subject that this building is known as Building L and its administrative section is located on the ground and first floors. Our research focuses specifically on these two floors, and we refrain from examining the remaining floors.

2.3.1 Problem statement and research questionnaire

Recognizing the problem that we had with the project was one of the most crucial aspects in the renovation procedure. In fact, understanding the idea of renovating for the need of spaces and the people who will use the spaces is crucial when we want to start a project, especially interior transformation. In this particular case, it is crucial that we look into and examine the issues, local conditions, and most importantly, the users. Therefore, the first step will be to immediately inquire about the wants and concerns of users, difficulties with the building, and any other factors that are essential to the employer and us as designers.

As I started to research about the project and department, this department belongs to different persona, such as employees, professors, managers and also some researchers who are using different parts of the department. So I have to consider all of these persona into my design and focus on their needs and accessibility.

In this scenario, we were going to use a multiple-choice questionnaire to ask about issues in order to determine the most significant problem and difficulty that users encounter on a daily basis. This questionnaire represented on the online platform, google form and responses are registered to find better solution about the project.

The questionnaire is listed below, and the next step is to analyze the answers:

Questionnaire

1.What are the main reasons for renovating the office space?

A) To improve employee productivity B) To reduce energy costs and improve sustainability

C) To improve the aesthetics and appearance of the space

2.Which design aspects should be considered when renovating the office space?

A) Lighting and natural light B) Furniture and layout

C) Color scheme and materials D) All of the above

3.What sustainable design aspects should be considered when renovating the office space?

A) Use of energy-efficient lighting fixtures and appliances

B) Implementation of a paperless policy and digital document storage

C) Use of eco-friendly building materials and furnishings

D) Incorporation of green spaces and plants to improve air quality

E) All of the above

4.What types of technology upgrades are needed for the office space?

A) Upgrading computer hardware and software B) Implementing digital displays and screens

C) Installing state-of-the-art teleconferencing equipment D) All of the above

5.What are the most important factors to consider in terms of employee comfort and well-being?

A) Ergonomic furniture and equipment B) Adequate lighting and ventilation

C) Noise reduction and soundproofing D) All of the above

6.What are the best ways to create collaborative spaces in the office?

A) Designating specific areas for group work and meetings

B) Installing interactive whiteboards and displays

C) Providing comfortable seating arrangements

D) All of the above

7.What type of flooring is the most suitable for an office space?

A) Carpet B) Hardwood C) Vinyl D) All of the above

8.What type of storage options should be considered for the renovated office space?

A) Filing cabinets and drawers B) Shelving units and bookcases

C) Storage closets and lockers D) All of the above

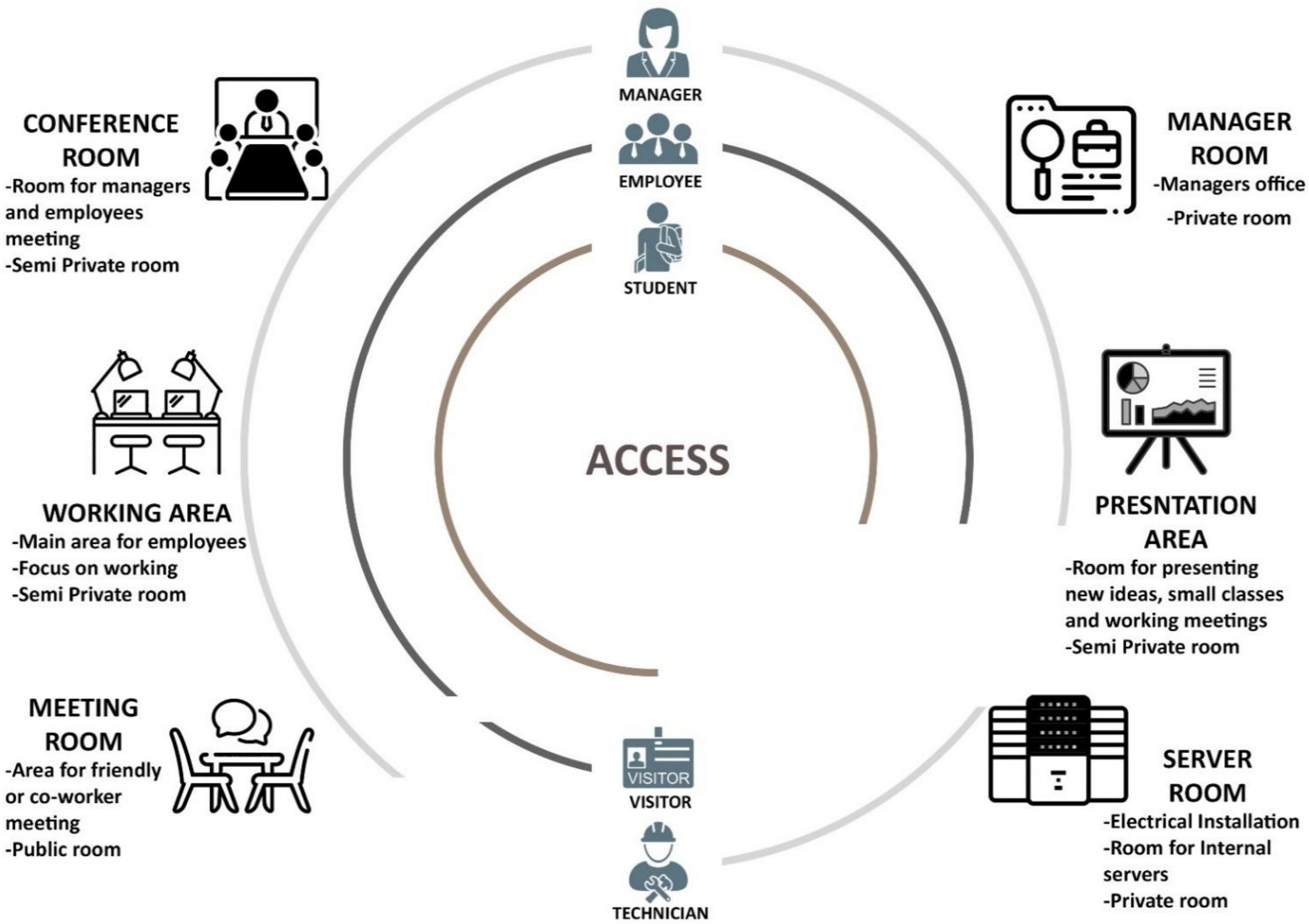


Fig 2.16 Hierarchy of access in the department

The second step was to analyze the answers. With this step, it could be useful to find out the issues and problems that is available in the department and should considered during design phase to renovate the offices in the best way. Below you can find the results of the questionnaire that we provide for the employer, employees, and professors who are using this department.

Above, you can see each persona's accessibility to the different rooms and areas. The personas that I researched about the department who are using the areas are:

1-Managers

2-Employees

3-Technician

4-visitors

Therefore, in this case, the department's privacy stage should be taken into consideration. This might lead to a lot of issues because it wouldn't be feasible to reach everyone in the region.

The initial stages of design via the department's renovation for sustainable and practical interior spaces have already begun.

The department's questionnaire revealed that the irritating noise within the building is another significant concern. For both employees and supervisors, noise is one of the main sources of distraction. It may also be referred to as "Noise Pollution.". Any undesirable or possibly disruptive sound that interferes with one's ability to focus and complete job tasks is referred to as noise distraction in workplaces. Conversations amongst coworkers, phone calls, printers, laptops, and other electronic gadgets are just a few of the many sources of noise distraction in offices. Noise distraction may be caused by even little sounds, such as a coworker tapping on a keyboard or the sound of footfall in the corridor.
It is commonly known that noise distraction has a detrimental impact on office workers. It can result in decreased output, more stress, and less work satisfaction. Noise distraction may also result in bodily symptoms like headaches and exhaustion and can be detrimental to one's general health and wellbeing.

There are a number of tactics that may be used to combat noise distraction in offices. One strategy is to establish quiet areas within the workplace where staff may congregate to focus without being distracted by noise. Another strategy is to help block out disturbing sounds by using sound masking techniques like white noise or music. Employers can also spend money on noise-cancelling equipment like acoustic panels or headphones to help lower noise levels in the workplace.

1- Install sound-absorbing materials: To absorb sound waves and lower noise levels, use acoustic panels, curtains, and -wall coverings. These products can be utilized in private offices, conference rooms, and other locations where noise is an issue.
2- To construct enclosed places where noise may be reduced, soundproof walls, doors, and windows should be installed. This may be particularly useful in conference rooms, individual offices, and other settings where focus is essential.
3- Use white noise generators to conceal distracting noises. White noise machines may be used to produce a steady background noise. These devices can be very helpful in open-plan offices with plenty of noise sources.

The fact that the department as a whole has too many closed rooms makes the work space much smaller and results in long, useless dark corridors, which is another issue that employees deal with during time work. In addition, the walls and paths take up an excessive amount of area.

As we now know, there exists another difficulty in reconstructing the department since, as a result of the issues mentioned above, the department would not be adaptable enough to add more staff. Naturally, they cannot increase the productivity of the employees and managers in this circumstance. Additionally, the lack of certain facilities for the staff members of this division causes a number of issues, such as the absence of meeting spaces, conference spaces, presentation spaces, and...

2.3.2 Objectives and Strategies

In this section, we discuss the objectives and strategies implemented in this research. The thesis aims to achieve the following objectives in two stages:

1- The first objective is to redesign and renovate the interior spaces of the ground and first floors of Building L. The client, considering their needs and the requirements of the workforce within these spaces (analyzing questionnaire results), seeks optimal and functional changes in these administrative areas. It should be noted that the changes should be limited to the interior design level only, as any demolition or alteration of external spaces would contradict the other university buildings. We will delve into these objectives and changes in detail later, but here, a brief overview is necessary. Creating new spaces for administrative tasks, ensuring circulation considering people's access upon entering the office, and modifying workspaces to increase the workforce are among the objectives.

2- In the second stage, which is the main focus of the thesis, the aforementioned changes must be carried out in accordance with the principles of sustainability in architecture. This means that when we introduce changes to the interior spaces, materials, dimensions, and other elements of these offices, we must consider sustainability. Ultimately, the most crucial issue for us is the overall energy analysis of these two spaces, taking into account the best available materials and the heating and cooling systems' impact on energy consumption.

In essence, our aim is to improve the architectural environment of the interior spaces and enhance their energy efficiency and sustainability."

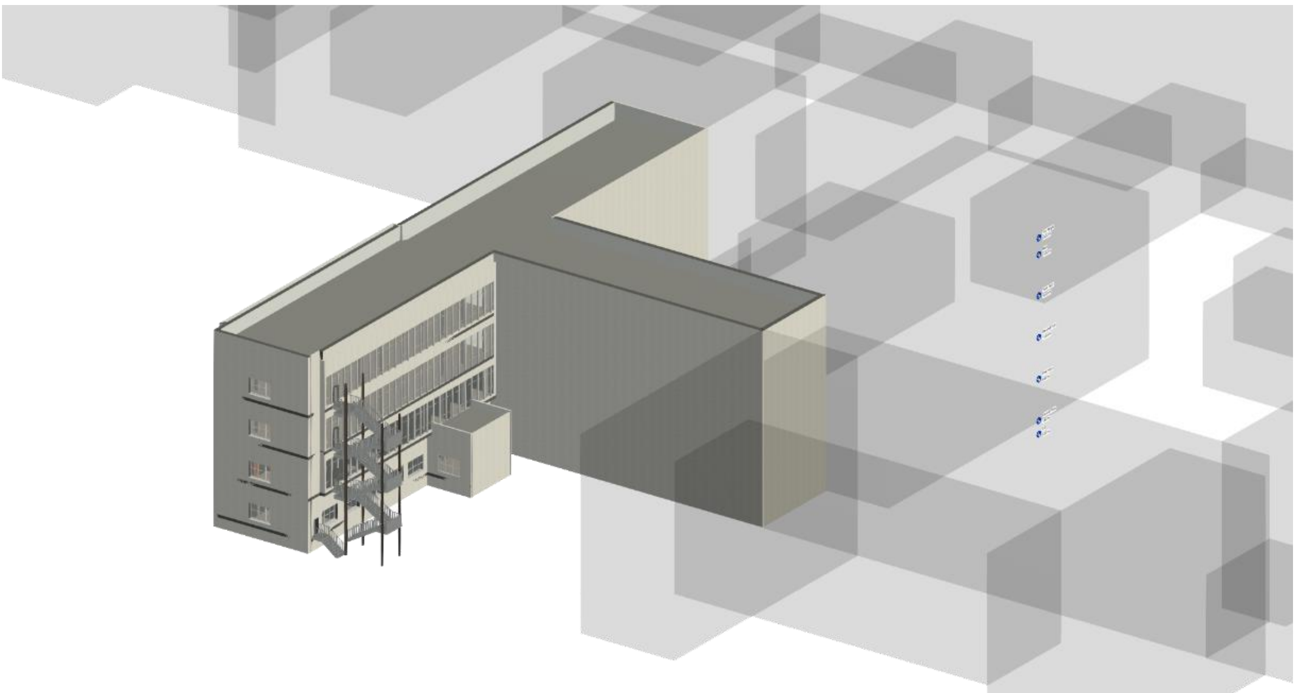


Fig 2.17 3D model of the building (Revit Software)

3. Methodology

3.1 Design and sustainable approaches POLITO

After completing extensive research on the best design solutions and sustainable ideas for the project, I arrived here to start planning interior spaces, selecting the materials that will be used in the office, and, finally, providing sustainable solutions to achieve a zero-energy building, which is a difficult task. As we all know, zero-energy buildings should be considered during all stages of the design process, from the beginning to the completion, as well as their life cycle costs.

However, I attempted to provide a variety of interior design and material possibilities since my goal was to find the best answer for this building. As predicted, variances in choosing alternatives provide varied results, which we may evaluate as a data set for the best answer in order to help BIM tools understand which material or design would be preferable for future restoration construction.

3.1.1 Interior redesign

Paying attention to the issue of interior design provides the designer with the opportunity to create an environment that meets the needs of the client while also addressing the topic of sustainability. By considering the use of space and taking sustainability into account, the designer can come up with the best solution. Since I became familiar with the problems of the polytechnic building through a questionnaire, I needed to initially consider those issues in my own design.

From the summary of studies and research on various case studies for office spaces, it appears that an open office design is the best option for modernizing such workplaces. However, it should be noted that this type of interior design may also create issues for individuals' privacy in the office. Nevertheless, the choice of this type of design was precisely to solve the main problems faced by the employees of this office. To ensure the privacy of individuals, solutions can be proposed to prevent members from experiencing any particular problems in establishing personal or work-related communications.

Initially, it is necessary to examine and analyze the current office layout plan to identify its weaknesses. By dividing the spaces, we can observe the exact placement of each use. The high number of enclosed offices, narrow and dark hallways, and lack of suitable spaces for meetings and business appointments, as well as the absence of an appropriate location for increasing the workforce and exchanging with students, are the main problems of this office.

The design of the ground floor and the first floor of this department has been addressed, and the remaining floors, both in terms of interior design and energy analysis of the building, are not included in this thesis.

Fig 3.1 Current plan (Ground floor)

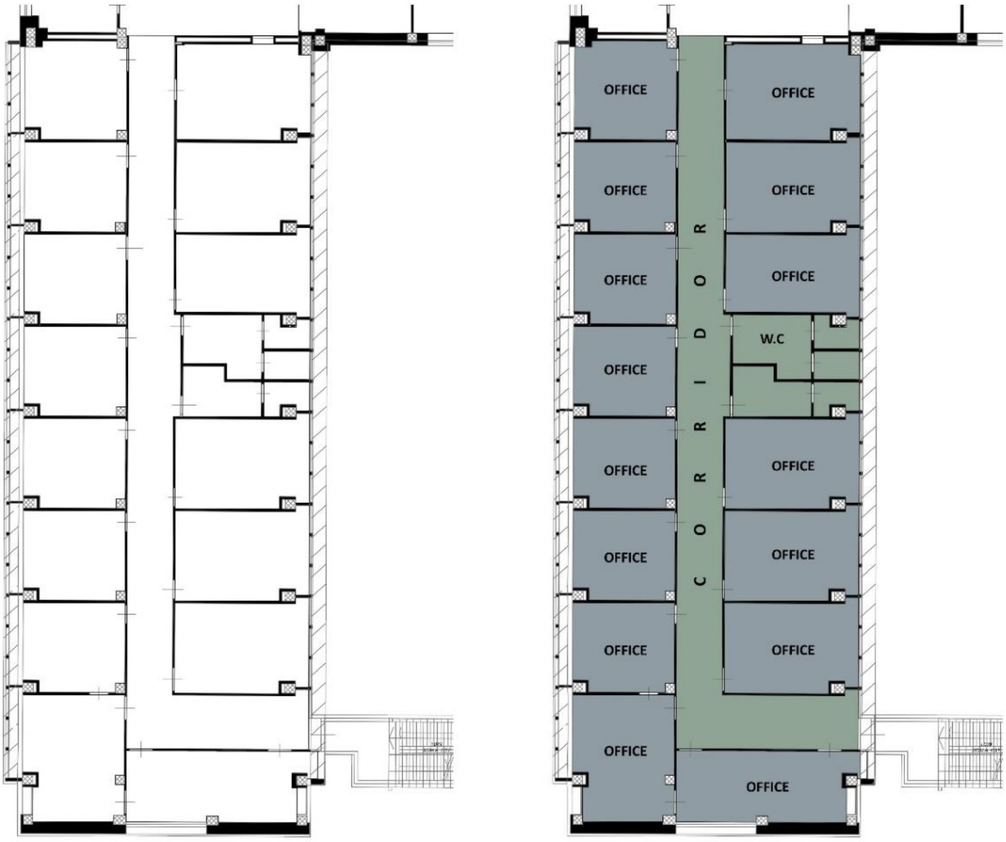


Fig 3.2 Current plan (First floor)

The University of Polytechnic Turin had another request for changes in the space of this department, which was to increase the space for new staff to be added to the department. This figure is approximately 15 to 20 percent higher than the current number of employees in the department. By examining the documents related to the department, it was determined that the current workforce in the office is as follows, according to the table below:

<Room Schedule>						
A	B	C	D	E	F	G
Number	Level	Name	Area	Volume	Occupancy	Perimeter
1	Ground Floor	Office	20 m²	81.84 m³	2	19.51 m
2	Ground Floor	Office	14 m²	51.68 m³	2	14.77 m
3	Ground Floor	Office	24 m²	91.28 m³	2	22.28 m
4	Ground Floor	Office	25 m²	93.37 m³	2	20.26 m
5	Ground Floor	Office	28 m²	108.01 m³	2	23.28 m
6	Ground Floor	Office	25 m²	93.26 m³	2	20.26 m
7	Ground Floor	Office	25 m²	93.53 m³	2	20.27 m
8	Ground Floor	Office	14 m²	52.47 m³	2	15.40 m
9	Ground Floor	Office	17 m²	63.13 m³	2	16.91 m
10	Ground Floor	Office	14 m²	54.69 m³	2	15.26 m
11	Ground Floor	Office	14 m²	54.22 m³	2	15.16 m
12	Ground Floor	Office	16 m²	62.10 m³	2	16.76 m
13	Ground Floor	Office	24 m²	91.87 m³	2	20.15 m
14	Ground Floor	Office	16 m²	62.42 m³	2	17.76 m
15	Ground Floor	Office	54 m²	204.95 m³	2	33.12 m
16	Ground Floor	Office	14 m²	52.34 m³	2	14.89 m
17	Ground Floor	Corridor	56 m²	213.51 m³	-	75.98 m
18	Ground Floor	W.C	22 m²	84.08 m³	-	19.47 m
19	First Floor	Office	21 m²	80.10 m³	2	20.13 m
20	First Floor	Office	27 m²	102.18 m³	2	21.60 m
21	First Floor	Office	19 m²	72.99 m³	2	18.57 m
22	First Floor	Office	24 m²	92.39 m³	2	21.14 m
23	First Floor	Office	17 m²	66.17 m³	2	18.20 m
24	First Floor	Office	22 m²	83.52 m³	2	19.64 m
25	First Floor	Office	19 m²	72.76 m³	2	18.88 m
26	First Floor	Office	24 m²	93.09 m³	2	21.21 m
27	First Floor	Office	19 m²	72.44 m³	2	18.77 m
28	First Floor	Office	19 m²	72.70 m³	2	18.83 m
29	First Floor	Office	25 m²	94.72 m³	2	21.40 m
30	First Floor	Office	19 m²	72.67 m³	2	18.88 m
31	First Floor	Office	25 m²	94.47 m³	2	21.42 m
32	First Floor	Office	27 m²	106.93 m³	2	22.19 m
33	First Floor	Office	24 m²	91.89 m³	2	24.56 m
34	First Floor	W.C	26 m²	97.52 m³	-	22.27 m
35	First Floor	Corridor	76 m²	287.38 m³	-	79.09 m
Grand total: 35			856 m²	3262.66 m³	62	

Table 3.1 Room Schedule for Building L (Polito)

To accommodate the increased employers, it should be noted that the existing rooms do not have the capacity for this expansion, and additional spaces need to be added to the office. Considering this, the option of adding new rooms was not feasible, and the interior space design system needed to be changed. Therefore, open-plan offices can be the best option for this space.

By examining relevant case studies, it was concluded that the interior space of the office is heavily occupied despite the consecutive walls. By removing these walls, a larger space can be created for employees and professors. However, it should be noted that such plans may create visual and auditory disturbances. One of the main issues we faced in designing this office was noise pollution. Great attention should be paid to the elements used in the interior space to address this problem.

The lack of meeting spaces for managers, professors, and even students, as well as the shortage of service areas and secretary spaces, were other factors that needed to be considered in the interior design. Increasing these spaces was not possible in itself, as all the rooms were designated for employees, and removing them would result in a shortage of workforce, contrary to the employer's idea. It was important to consider that individuals' interaction with these spaces should be limited to their needs and that a hierarchical spatial arrangement should be maintained. This was another challenge we faced.

As AutoCAD file provided by the university was utilized to initiate the drawing process in the software Revit. Consequently, by effectively modeling the Building Information Model (BIM), I was able to easily access all the construction details. Many of these details are subsequently presented herein and are utilized for energy analysis of the building, interior space analysis, and even construction cost analysis. This is precisely where the advantage of BIM and Revit comes into play. By modeling the structural details, we can effortlessly obtain access to all the relevant information. The current project plans are depicted in the Revit views above.

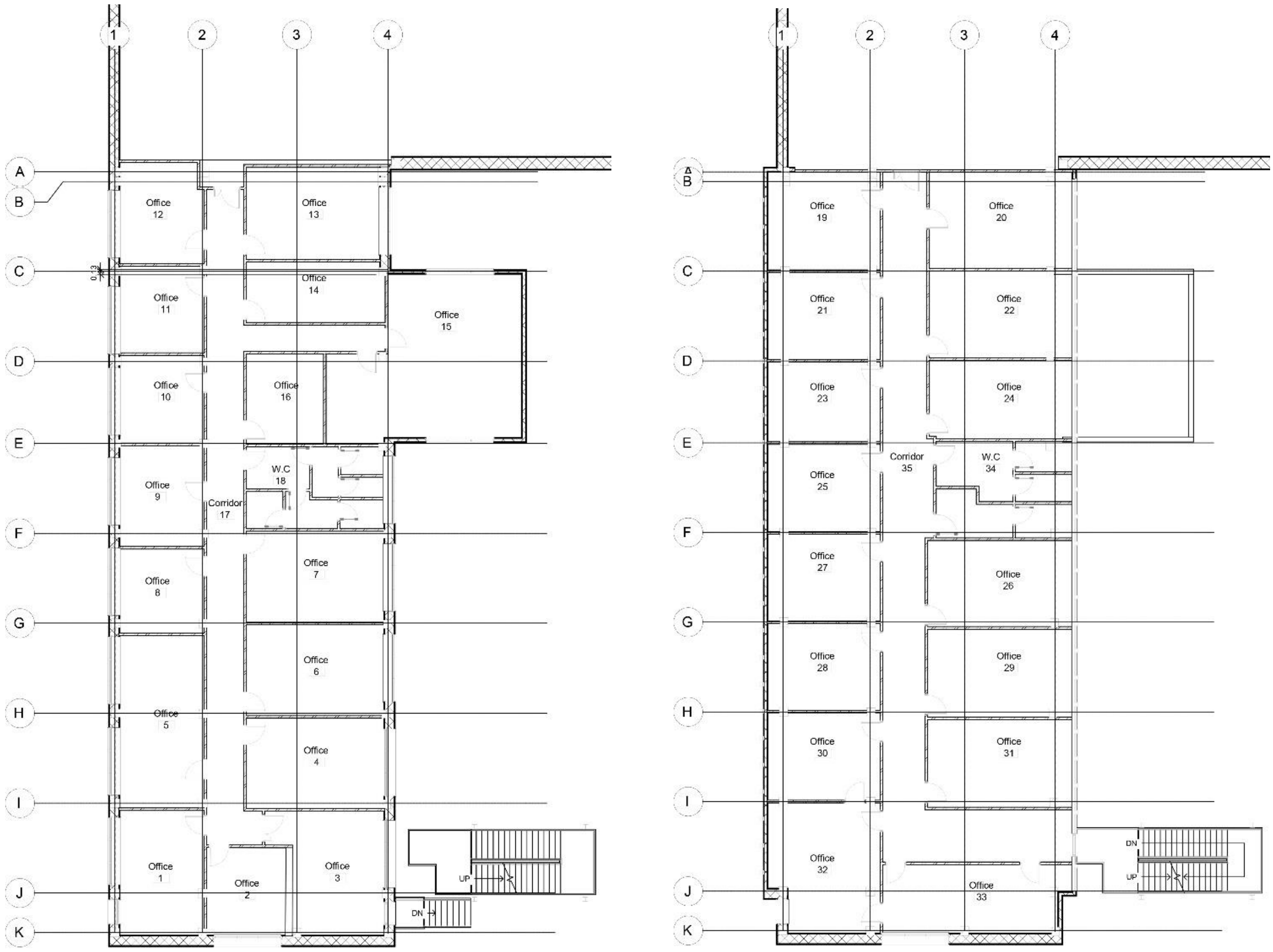


Fig 3.3 Ground and First floors of BIM export

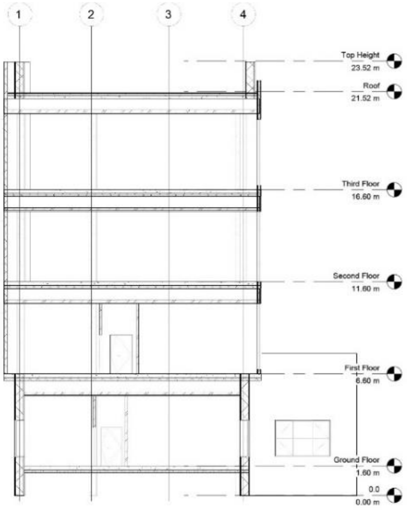
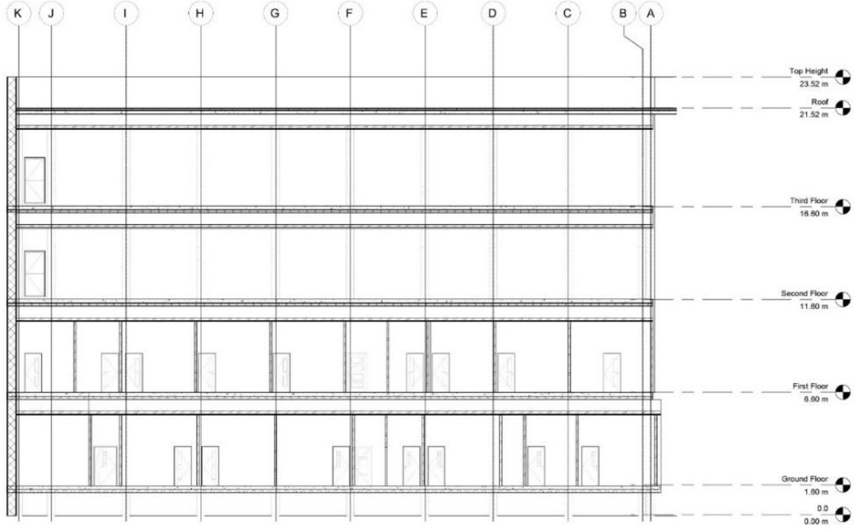


Fig 3.4 Section A-A



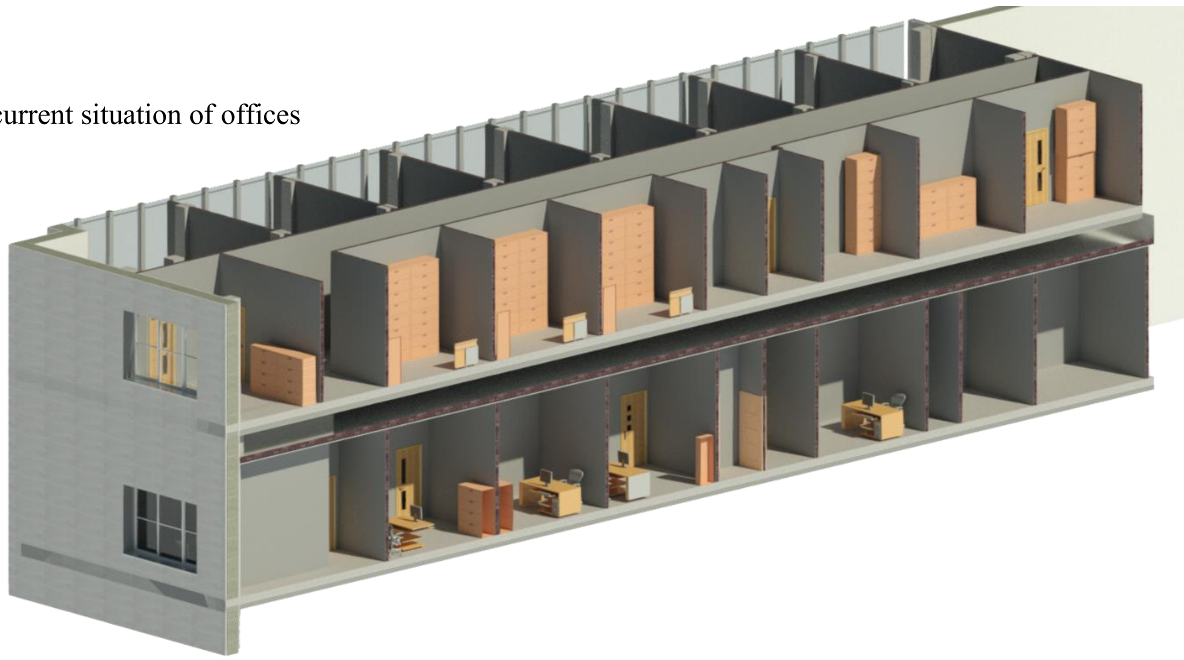
Section B-B

In Revit, a wall schedule is a table or statistical representation of wall parts in a building model. It gives a thorough overview of the project's walls, allowing users to obtain and evaluate critical information about each wall part. Here are some major components of a Revit wall schedule:

A wall schedule includes information on each wall's kind, height, breadth, thickness, placement, and elevation. This information aids in comprehending the qualities and measurements of the building's walls. Also, The schedule provides precise quantity takeoffs and cost estimations for materials, labor, and other project-related expenditures by supplying amounts and measurements for each wall type. This information is useful for budgeting and procurement.

Wall schedules may be adjusted to incorporate additional characteristics such as room associations, wall tags, phase status, and other user-defined variables for project organization and coordination. This aids in the organization and coordination of the walls within the context of the larger project. Designers and project stakeholders can acquire insights into the distribution and features of walls throughout the building by examining the wall schedule. This can lead to the identification of design inefficiencies, the optimization of material utilization, and the improvement of building processes.Documentation and Collaboration: Wall schedules serve as a clear and succinct documentation tool, allowing project team members to communicate and collaborate more effectively. It facilitates the exchange and display of information about walls during design reviews, construction coordination meetings, and facility management.

Fig 3.5 3D section of current situation of offices



One of the most important pieces of information that we can access through the wall schedule is the current situation of the building. Thermal resistance and thermal mass of different elements of walls from whole of the building. For energy analysis, thermal resistance and thermal mass of a wall have a major influence on a building's energy load. The capacity of a wall to resist heat transmission is measured by thermal resistance, which is frequently expressed by the R-value. A higher R-value implies better insulation and less heat transfer through the wall. Thermally resistant walls assist in maintaining a constant indoor temperature by reducing heat movement between the interior and outside surroundings. This decreases the building's dependency on heating and cooling systems, resulting in lower energy loads and higher energy efficiency.

A wall's thermal mass, on the other hand, relates to its ability to absorb, store, and release heat. Walls having high thermal mass, such as those composed of concrete or masonry, can retain heat during the day and slowly release it at night or during colder times. This aids in the stabilization of interior temperature changes by dampening the impact of external temperature swings. Buildings can decrease the need for mechanical heating and cooling by utilizing the thermal mass of their walls, resulting in lower energy needs and enhanced thermal comfort.

<Wall Schedule>								
A	B	C	D	E	F	G	H	I
Area	Length	Width	Family and Type	Count	Base Constraint	Top Constraint	Thermal Resistance	Thermal Mass
5.06 m²	1.21 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
3.17 m²	1.39 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
3.16 m²	1.62 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
4.58 m²	1.76 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
4.86 m²	2.07 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
7.20 m²	2.21 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
5.18 m²	2.36 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
6.84 m²	2.36 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
8.97 m²	2.92 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
12.55 m²	3.50 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
11.54 m²	3.59 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
12.56 m²	3.72 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
12.99 m²	3.74 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
13.42 m²	3.79 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
14.19 m²	4.05 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
14.19 m²	4.05 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
14.19 m²	4.05 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
14.19 m²	4.05 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
14.19 m²	4.05 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
15.27 m²	4.14 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
23.06 m²	6.13 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
23.12 m²	6.14 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
24.91 m²	6.24 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
22.48 m²	6.24 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
21.52 m²	6.29 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
23.44 m²	6.29 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
23.19 m²	6.42 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
23.19 m²	6.42 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
23.19 m²	6.42 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
22.86 m²	7.03 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
68.15 m²	20.34 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
112.54 m²	33.47 m	0.12 m	Basic Wall: Generic - 120mm	1	Ground Floor	Up to level: First Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
1.16 m²	0.31 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
2.60 m²	0.69 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
7.22 m²	1.90 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
9.51 m²	2.67 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
15.71 m²	4.30 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
10.88 m²	4.42 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
13.31 m²	4.53 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
17.03 m²	5.16 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
18.95 m²	5.16 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
18.95 m²	5.16 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
18.95 m²	5.16 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
18.95 m²	5.16 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
18.95 m²	5.16 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
18.95 m²	5.16 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
22.93 m²	6.20 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
24.09 m²	6.51 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
24.09 m²	6.51 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
24.83 m²	6.58 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
24.37 m²	6.58 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
24.37 m²	6.58 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
24.37 m²	6.58 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
28.13 m²	8.58 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
38.97 m²	11.89 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
39.86 m²	12.00 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
46.44 m²	13.00 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
111.63 m²	34.24 m	0.12 m	Basic Wall: Generic - 120mm	1	First Floor	Up to level: Second Floor	0.2037 (m²·K)/W	143.22 kJ/(m²·K)
Basic Wall: Generic - 1	358.29 m			58				
38.16 m²	5.97 m	0.22 m	Basic Wall: Generic - 220mm	1	0.0	Up to level: First Floor	0.9308 (m²·K)/W	215.06 kJ/(m²·K)
42.82 m²	6.16 m	0.22 m	Basic Wall: Generic - 220mm	1	0.0	Up to level: First Floor	0.9308 (m²·K)/W	215.06 kJ/(m²·K)
54.81 m²	7.48 m	0.22 m	Basic Wall: Generic - 220mm	1	0.0	Up to level: First Floor	0.9308 (m²·K)/W	215.06 kJ/(m²·K)
293.98 m²	12.50 m	0.22 m	Basic Wall: Generic - 220mm	1	0.0	Up to level: Top Height	0.9308 (m²·K)/W	215.06 kJ/(m²·K)
690.09 m²	28.93 m	0.22 m	Basic Wall: Generic - 220mm	1	0.0	Up to level: Top Height	0.9308 (m²·K)/W	215.06 kJ/(m²·K)
6.38 m²	0.62 m	0.22 m	Basic Wall: Generic - 220mm	1	First Floor	Up to level: Top Height	0.9308 (m²·K)/W	215.06 kJ/(m²·K)
14.04 m²	0.74 m	0.22 m	Basic Wall: Generic - 220mm	1	First Floor	Up to level: Top Height	0.9308 (m²·K)/W	215.06 kJ/(m²·K)
31.35 m²	2.01 m	0.22 m	Basic Wall: Generic - 220mm	1	First Floor	Up to level: Top Height	0.9308 (m²·K)/W	215.06 kJ/(m²·K)
168.29 m²	32.23 m	0.22 m	Basic Wall: Generic - 220mm	1	First Floor	Up to level: Roof	0.9308 (m²·K)/W	215.06 kJ/(m²·K)
193.45 m²	32.30 m	0.22 m	Basic Wall: Generic - 220mm	1	First Floor	Up to level: Roof	0.9308 (m²·K)/W	215.06 kJ/(m²·K)
Basic Wall: Generic - 2	128.94 m			10				
19.38 m²	4.20 m	0.30 m	Basic Wall: Generic - 300mm	1	Ground Floor	Up to level: First Floor		
Basic Wall: Generic - 3	4.20 m			1				
265.54 m²	11.29 m	0.61 m	Basic Wall: Generic - 520mm	1	0.0	Up to level: Top Height	1.2308 (m²·K)/W	804.74 kJ/(m²·K)
837.32 m²	36.02 m	0.61 m	Basic Wall: Generic - 520mm	1	0.0	Up to level: Top Height	1.2308 (m²·K)/W	804.74 kJ/(m²·K)
858.72 m²	36.47 m	0.61 m	Basic Wall: Generic - 520mm	1	0.0	Up to level: Top Height	1.2308 (m²·K)/W	804.74 kJ/(m²·K)
Basic Wall: Generic - 5	83.77 m			3				
25.38 m²	4.84 m	0.52 m	Basic Wall: Generic - 520mm 2	1	0.0	Up to level: First Floor	1.1538 (m²·K)/W	653.54 kJ/(m²·K)
275.92 m²	12.38 m	0.52 m	Basic Wall: Generic - 520mm 2	1	0.0	Up to level: Top Height	1.1538 (m²·K)/W	653.54 kJ/(m²·K)
113.87 m²	22.28 m	0.52 m	Basic Wall: Generic - 520mm 2	1	0.0	Up to level: First Floor	1.1538 (m²·K)/W	653.54 kJ/(m²·K)
442.02 m²	74.81 m	0.52 m	Basic Wall: Generic - 520mm 2	1	0.0	Up to level: First Floor	1.1538 (m²·K)/W	653.54 kJ/(m²·K)
15.03 m²	0.74 m	0.52 m	Basic Wall: Generic - 520mm 2	1	First Floor	Up to level: Top Height	1.1538 (m²·K)/W	653.54 kJ/(m²·K)
17.15 m²	2.01 m	0.52 m	Basic Wall: Generic - 520mm 2	1	First Floor	Up to level: Top Height	1.1538 (m²·K)/W	653.54 kJ/(m²·K)
682.06 m²	40.57 m	0.52 m	Basic Wall: Generic - 520mm 2	1	First Floor	Up to level: Top Height	1.1538 (m²·K)/W	653.54 kJ/(m²·K)
63.85 m²	32.30 m	0.52 m	Basic Wall: Generic - 520mm 2	1	Roof	Up to level: Top Height	1.1538 (m²·K)/W	653.54 kJ/(m²·K)
64.46 m²	32.59 m	0.52 m	Basic Wall: Generic - 520mm 2	1	Roof	Up to level: Top Height	1.1538 (m²·K)/W	653.54 kJ/(m²·K)
Basic Wall: Generic - 5	222.51 m			9				
120.90 m²	31.82 m		Curtain Wall: Curtain Wall 2	1	First Floor	Up to level: Second Floor		
111.27 m²	31.88 m		Curtain Wall: Curtain Wall 2	1	First Floor	Up to level: Second Floor		
118.56 m²	31.77 m		Curtain Wall: Curtain Wall 2	1	Second Floor	Up to level: Third Floor		
120.90 m²	31.82 m		Curtain Wall: Curtain Wall 2	1	Second Floor	Up to level: Third Floor		
111.27 m²	31.77 m		Curtain Wall: Curtain Wall 2	1	Third Floor	Up to level: Roof		
120.90 m²	31.82 m		Curtain Wall: Curtain Wall 2	1	Third Floor	Up to level: Roof		
Curtain Wall: Curtain	190.87 m			6				

Table 3.2 Wall schedule of building L

After considering several alternative designs to create a suitable interior space based on the mentioned needs and approaches, we have reached the conclusion that the preferred option for the employer is the following plan:

Fig 3.6 Project spaces diagram (Ground and First floor)

As evident, apart from the restroom, all spaces have been changed, and the new required spaces have been incorporated into this office. One notable aspect is the presence of telephones. As mentioned, one of the main issues in this office was excessive noise pollution during phone conversations. This problem has been addressed by providing fully isolated and acoustically treated spaces for phone conversations.

Additionally, other elements have been incorporated into the interior spaces that contribute significantly to both visual appeal and sustainability. The presence of green elements for air conditioning and visual changes to prevent visual and mental fatigue is highly effective. Another significant development is the expansion in open workplace environments for office workers. These places allow us to meet the employer's desire for a 20% expansion in the workforce. Aside from that, all of the essential office spaces have been efficiently distributed.

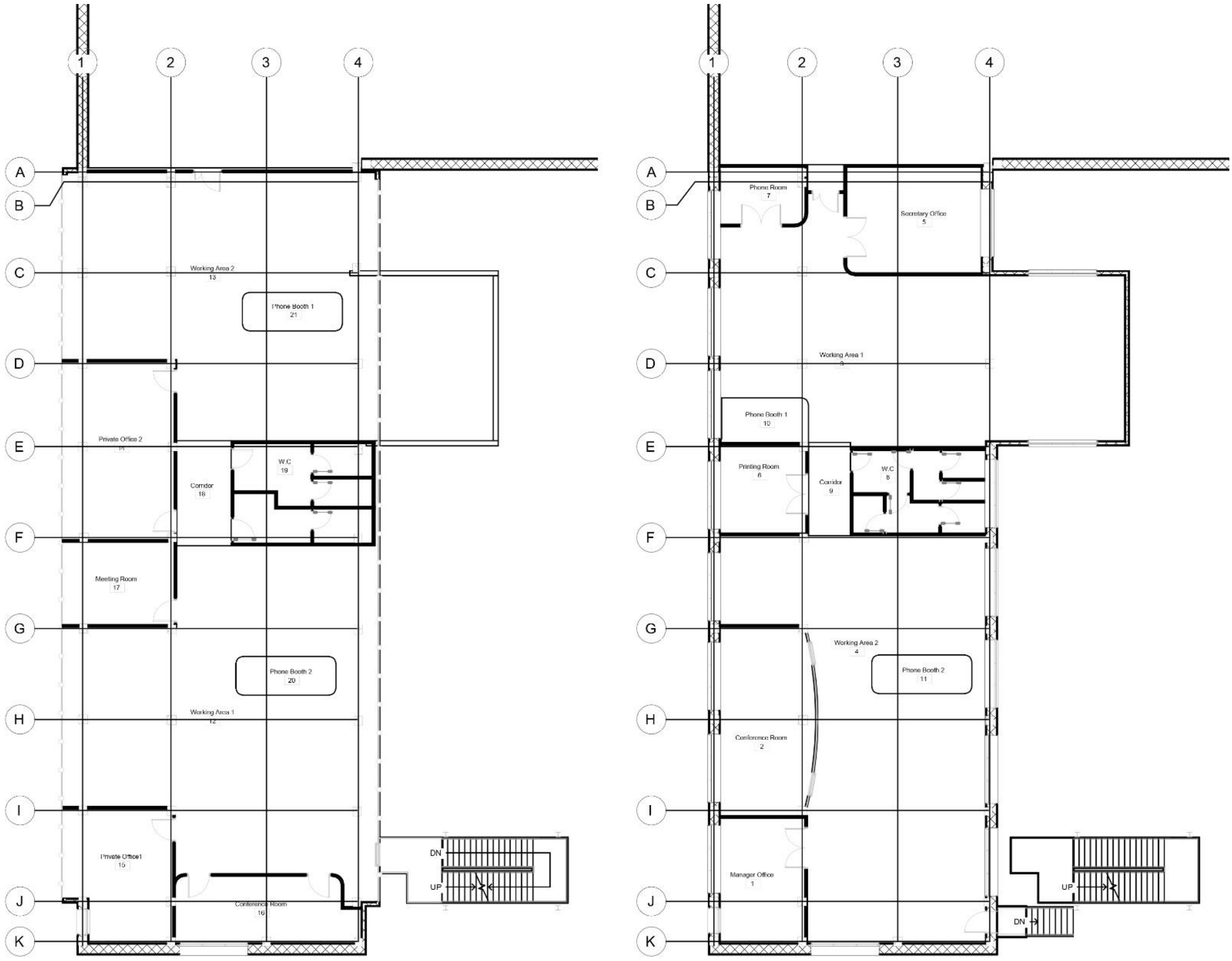


Fig 3.7 Project designed plans (Right : First floor, Left : Ground floor)

Fig 3.8 Section A-A (project) Section B-B (project)

The modifications made to the interior space of the office building have proven to be largely satisfactory in meeting the client's requirements and project needs, both in terms of design and the comfort of occupants as well as energy consumption. Increasing the workforce was of great importance to the client, and open office spaces provide the opportunity to allocate more space for employees by eliminating unnecessary walls, with only a limited number of rooms with walls reserved for important and private meetings as well as conference areas. By removing long and dark corridors and incorporating them into usable space, as well as introducing natural light into the building without walls, significant energy savings have been achieved, reaching their lowest levels. Another positive aspect of this type of floor plan is the provision of spaces for telephone conversations with acoustic partitions, which contributes to reducing sound pollution in the office environment.

<Room Schedule>						
A	B	C	D	E	F	G
Number	Name	Area	Level	Occupancy	Volume	Perimeter
1	Manager Office	20 m²	Ground Floor	3	77.01 m³	18.87 m
2	Conference Room	33 m²	Ground Floor	14	125.47 m³	24.05 m
3	Working Area 1	137 m²	Ground Floor	24	549.87 m³	61.08 m
4	Working Area 2	145 m²	Ground Floor	22	551.87 m³	60.84 m
5	Secretary Office	27 m²	Ground Floor	6	104.18 m³	21.19 m
6	Printing Room	14 m²	Ground Floor	2	54.93 m³	15.25 m
7	Phone Room	9 m²	Ground Floor	4	34.48 m³	12.88 m
8	W.C	21 m²	Ground Floor	-	80.23 m³	18.91 m
9	Corridor	8 m²	Ground Floor	-	28.59 m³	11.87 m
10	Phone Booth 1	8 m²	Ground Floor	2	28.70 m³	11.46 m
11	Phone Booth 2	7 m²	Ground Floor	2	28.13 m³	11.68 m
12	Working Area 1	157 m²	First Floor	20	597.08 m³	60.91 m
13	Working Area 2	133 m²	First Floor	20	507.01 m³	55.06 m
14	Private Office 2	36 m²	First Floor	8	136.42 m³	26.59 m
15	Private Office1	25 m²	First Floor	6	95.26 m³	22.06 m
16	Conference Room	22 m²	First Floor	10	85.24 m³	22.55 m
17	Meeting Room	17 m²	First Floor	3	64.36 m³	16.60 m
18	Corridor	11 m²	First Floor	-	41.80 m³	14.00 m
19	W.C	8 m²	First Floor	-	30.57 m³	12.30 m
20	Phone Booth 2	7 m²	First Floor	2	28.13 m³	11.68 m
21	Phone Booth 1	7 m²	First Floor	2	28.13 m³	11.68 m
Grand total: 21		855 m²			3277.45 m³	

Table 3.3 Room schedule for project

By examining the furnished plan above, we can identify several important points:

1- To address the issue of noise pollution during office hours, particularly during phone conversations, telephone stations have been included. Employees can comfortably make phone calls in these designated areas without causing disruptions.
2- The presence of space dividers in the form of green separators (plant stands) not only contributes to a visual change in the space but also provides employees with visual rest and creates a refreshing atmosphere by generating oxygen.

3- In the ground floor conference room, we observe partition dividers that can be used to divide the room according to the number of people present.

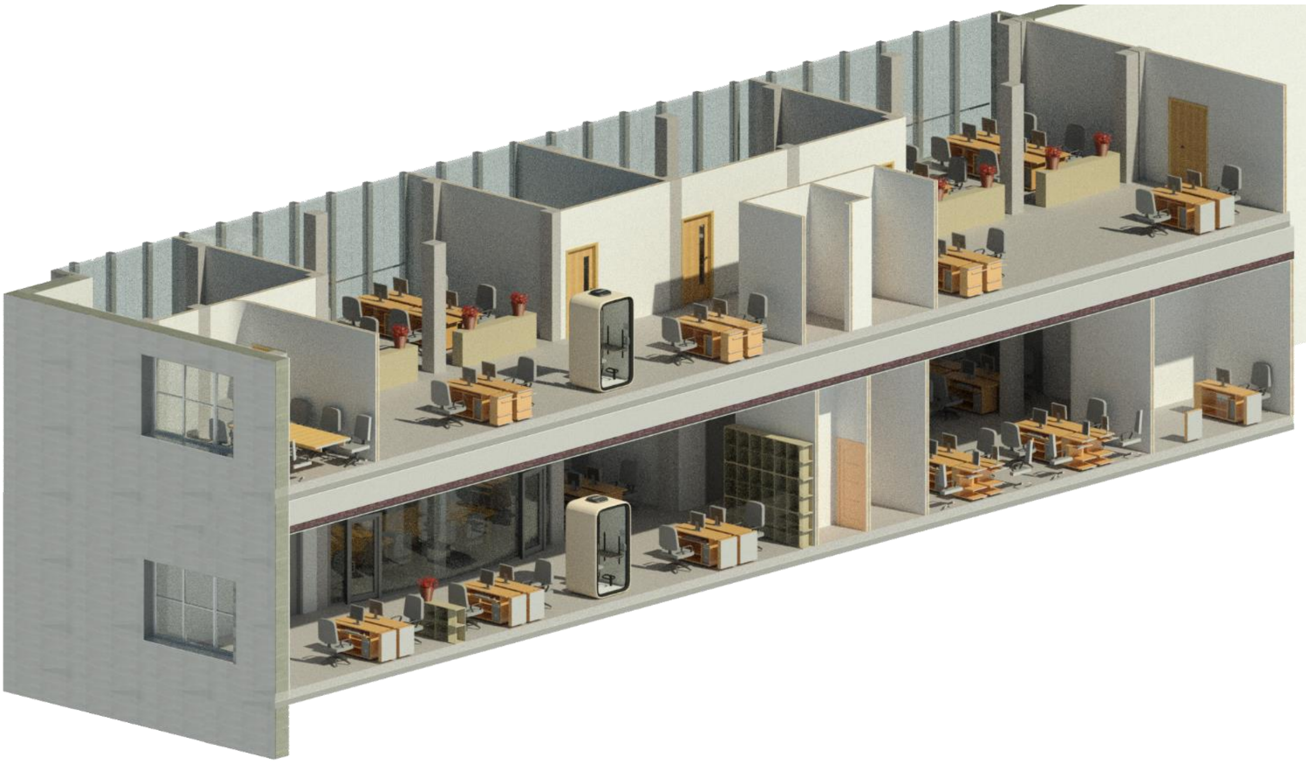


Fig 3.9 3D section of project situation after renovation

The transition from traditional room-based offices to open work spaces is a fundamental departure in modern working environments. This transition entails removing physical boundaries and fostering a more collaborative and linked environment. By removing distinct rooms and replacing them with an open structure, the interior environment becomes more favorable to improved communication, cooperation, and creativity. The absence of barriers generates a sense of shared purpose and enables coworkers to communicate spontaneously. Furthermore, an open work area design promotes more effective use of space by optimizing square footage and permitting adaptable configurations that may adapt to the organization's changing needs.

One of the most noticeable benefits of transforming the interior space to an open work environment is the ability to utilize natural sunshine while reducing dependency on artificial lighting. By eliminating typical corridors and creating open design, natural light is maximized and permeates the workstation. Natural light has been shown to improve human well-being, productivity, and general contentment. Increased exposure to sunshine can help employees have a better mood, feel less tired, and concentrate better. Furthermore, using less artificial lighting decreases not just energy consumption and related expenses, but also encourages a more ecologically friendly workplace. The incorporation of plenty of natural light into the open work space design generates a healthier and more lively environment, favorably impacting the mental state and performance of employees within the business.

A	B	C	D	E	F	G	H	I
Family and Type	Length	Area	Width	Cost	Base Constraint	Top Constraint	Thermal Resistance	Thermal Mass
Basic Wall: Generic - 100mm- curtain	7.70 m	10 m^2	0.10 m		Ground Floor	Up to level: First Floor		
Basic Wall: Generic - 100mm- curtain: 1	7.70 m			0.00€				
Basic Wall: Generic - 120mm - Mat	1.71 m	3 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.06 m	15 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	6.24 m	25 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	6.14 m	23 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	6.14 m	23 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	2.63 m	8 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	2.32 m	5 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	3.51 m	13 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	2.32 m	7 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	2.22 m	7 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	1.76 m	5 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	1.43 m	3 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.09 m	15 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	3.98 m	11 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	3.75 m	12 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.09 m	14 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	5.82 m	21 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.35 m	12 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	0.66 m	3 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	3.71 m	13 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.04 m	14 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	5.81 m	17 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	2.10 m	8 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	3.53 m	9 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	0.82 m	3 m^2	0.12 m	55.00€	Ground Floor	Up to level: First Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	6.20 m	24 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.50 m	13 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	12.96 m	46 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	6.37 m	24 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	1.91 m	7 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	0.69 m	3 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.46 m	16 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.50 m	11 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	2.70 m	10 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	6.21 m	21 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.92 m	18 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	6.49 m	20 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.98 m	19 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.98 m	19 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	11.65 m	38 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.98 m	19 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	0.75 m	3 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	1.01 m	4 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	0.69 m	3 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	0.93 m	3 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat	4.50 m	22 m^2	0.12 m	55.00€	First Floor	Up to level: Third Floor	0.0462 (m^2·K)/W	27.72 kJ/(m^2·K)
Basic Wall: Generic - 120mm - Mat: 46	183.61 m			2530.00€				
Basic Wall: Generic - 220mm	5.96 m	38 m^2	0.22 m		0.0	Up to level: First Floor	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	6.16 m	43 m^2	0.22 m		0.0	Up to level: First Floor	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	28.97 m	690 m^2	0.22 m		0.0	Up to level: Top Height	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	12.46 m	284 m^2	0.22 m		0.0	Up to level: Top Height	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	7.48 m	55 m^2	0.22 m		0.0	Up to level: First Floor	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	1.97 m	31 m^2	0.22 m		First Floor	Up to level: Top Height	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	0.61 m	6 m^2	0.22 m		First Floor	Up to level: Top Height	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	32.22 m	160 m^2	0.22 m		First Floor	Up to level: Roof	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	32.12 m	152 m^2	0.22 m		First Floor	Up to level: Roof	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	0.94 m	14 m^2	0.22 m		First Floor	Up to level: Top Height	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	0.79 m	15 m^2	0.22 m		First Floor	Up to level: Top Height	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	32.54 m	64 m^2	0.22 m		Roof	Up to level: Top Height	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm	32.23 m	64 m^2	0.22 m		Roof	Up to level: Top Height	0.9308 (m^2·K)/W	215.06 kJ/(m^2·K)
Basic Wall: Generic - 220mm: 13	194.45 m			0.00€				
Basic Wall: Generic - 520mm	40.58 m	954 m^2	0.52 m		0.0	Up to level: Top Height	1.5538 (m^2·K)/W	653.56 kJ/(m^2·K)
Basic Wall: Generic - 520mm	36.42 m	857 m^2	0.52 m		0.0	Up to level: Top Height	1.5538 (m^2·K)/W	653.56 kJ/(m^2·K)
Basic Wall: Generic - 520mm: 2	77.00 m			0.00€				
Basic Wall: Generic - 520mm 2	34.25 m	174 m^2	0.52 m		0.0	Up to level: First Floor	1.1538 (m^2·K)/W	653.54 kJ/(m^2·K)
Basic Wall: Generic - 520mm 2	22.24 m	114 m^2	0.52 m		0.0	Up to level: First Floor	1.1538 (m^2·K)/W	653.54 kJ/(m^2·K)
Basic Wall: Generic - 520mm 2	4.85 m	25 m^2	0.52 m		0.0	Up to level: First Floor	1.1538 (m^2·K)/W	653.54 kJ/(m^2·K)
Basic Wall: Generic - 520mm 2	12.34 m	275 m^2	0.52 m		0.0	Up to level: Top Height	1.1538 (m^2·K)/W	653.54 kJ/(m^2·K)
Basic Wall: Generic - 520mm 2	11.29 m	266 m^2	0.52 m		0.0	Up to level: Top Height	1.1538 (m^2·K)/W	653.54 kJ/(m^2·K)
Basic Wall: Generic - 520mm 2	35.97 m	837 m^2	0.52 m		0.0	Up to level: Top Height	1.1538 (m^2·K)/W	653.54 kJ/(m^2·K)
Basic Wall: Generic - 520mm 2	2.13 m	24 m^2	0.52 m		First Floor	Up to level: Top Height	1.1538 (m^2·K)/W	653.54 kJ/(m^2·K)
Basic Wall: Generic - 520mm 2: 7	123.06 m			0.00€				
Curtain Wall: Curtain Wall 2	31.82 m	121 m^2			First Floor	Up to level: Third Floor		
Curtain Wall: Curtain Wall 2	31.88 m	119 m^2			First Floor	Up to level: Third Floor		
Curtain Wall: Curtain Wall 2	31.88 m	119 m^2			Third Floor	Up to level: Fourth Floor		
Curtain Wall: Curtain Wall 2	31.82 m	121 m^2			Third Floor	Up to level: Fourth Floor		
Curtain Wall: Curtain Wall 2	31.88 m	111 m^2			Fourth Floor	Up to level: Roof		
Curtain Wall: Curtain Wall 2	31.82 m	121 m^2			Fourth Floor	Up to level: Roof		
Curtain Wall: Curtain Wall 2: 6	191.09 m			0.00€				
Curtain Wall: Curtain Wall- inside project	7.72 m	29 m^2			Ground Floor	Up to level: First Floor		
Curtain Wall: Curtain Wall- inside project:	7.72 m			0.00€				
Grand total: 76	784.63 m			2530.00€				

Table 3.4 Wall schedule of project after renovation

The modifications made to the interior space of the building were far below my expectations. Despite these changes, the impact on the energy load of the building is unlikely to be significantly different, which posed a major challenge for us. This challenge greatly limited our options. As a result, the alterations to the main structural walls of the building were minimal, and we could only focus on improving the insulation of the exterior walls to the best of our abilities. However, we had much more flexibility in making changes to the interior spaces and walls, which ultimately benefited the employees and faculty members.

3.1.2 Material selection

Several elements should be addressed while doing a sustainable wall analysis. Here are some important elements to consider when doing your analysis:

- Thermal performance: Examine the insulation qualities of the wall, such as thermal conductivity, R-value (heat flow resistance), and U-value (total thermal transmittance). Better insulation and energy efficiency are indicated by a higher R-value and a lower U-value.

- Consider the environmental effects of the wall material, such as embodied energy, carbon footprint, and life cycle assessment (LCA). Look for materials that have a low embodied energy and carbon footprint, as well as those that can be recycled or have a minimal environmental effect throughout manufacture, use, and disposal.

- Renewable and recycled content: Assess the use of renewable and recycled materials in the building of the wall. Choosing materials that include a high proportion of recycled content or are generated from renewable resources will help to limit resource depletion and trash creation.

- Indoor air quality: Evaluate the wall's influence on indoor air quality. Look for materials with low volatile organic compounds (VOCs) and little off-gassing. Indoor air quality improves occupant health and comfort.

- Durability and upkeep: Think about the lifetime and durability of the wall material. Sustainable walls should have a long lifespan, need little maintenance, and be resistant to environmental conditions. Durable walls eliminate the need for frequent replacements, lowering waste creation.

- Water and moisture management: Consider how the wall material regulates moisture and prevents intrusion or condensation. Moisture control is critical for preventing mold formation, preserving structural integrity, and maintaining a healthy interior environment.

- Local availability and sourcing: Consider the wall material's local availability and sourcing. Using locally accessible resources saves transportation-related energy consumption while also benefiting the local economy.

- Social considerations: Consider any social implications of the wall material, such as labor conditions, social fairness, and community effect. Sustainable walls should be manufactured and built in a fair and ethical manner.

3.1.2.1 Selected material

Some widely utilized alternatives for insulation materials with a low U-value (high thermal resistance) and a high R-value for walls include:

1- Spray foam insulation has a high R-value per inch and serves as an efficient air barrier, decreasing heat transmission and lowering energy loss. It can be used on a variety of wall types and has great thermal performance.

HIGH-DENSITY	MEDIUM-DENSITY	LOW-DENSITY
3 lbs./cubic ft., closed-cell foam	2 lbs./cubic ft., closed-cell foam	0.5 lbs./cubic ft., open-cell foam
R-Values start at 5.5 per inch*	R-Values start at 5.7 per inch*	R-Values start at 3.6 per inch*
Often used for exterior and roofing applica`tions	Often used for continuous insulation, interior wall cavity fill, and unvented attic applications	Often used for interior wall cavity fill and unvented attic applications

Fig 3.10 Spray foam insulation during installation

Fig 3.11 Spray foam insulation after Instalation

2- Rigid foam insulation has high R-values and low U-values, such as extruded polystyrene (XPS) or polyisocyanurate (ISO). They provide continuous insulation, are resistant to moisture, and may be put on the outside or inside of walls.

Expanded polystyrene (EPS)	Extruded polystyrene (XPS)	Polyisocyanurate (Polyiso, ISO)
		
•The most versatile of the three rigid insulation options •Used in Roof, Wall, Floor, Below Grade & Structural GeoFoam applications •Used most widely in insulated concrete forms and structural insulated panels •Highest average R-value per dollar (about 4.6 R per inch) – costs the least, while meeting or exceeding all required building and energy codes •Approved for ground contact, below grade applications and can be treated to resist insects •Does not retain water over the long term •Should be used over house wrap, or with a product that incorporates a factory laminated option •Available faced or unfaced •Faced products are considered vapor retardant and specialty products are considered vapor barriers •Warrant 100% of R-value over the long term since does not degrade over time	•Easily recognized by its blue, green, or pink color •Falls in the middle of the three types of rigid-foam insulation in both cost and R-value •Used most in walls or below grade applications •Recyclable, and at about R-5 per inch, costs around 42¢ per sq. ft. for a 1-in.-thick 4×8 panel •Comes unfaced or with a number of different plastic facings •Unfaced 1-in.-thick has a perm rating around 1, making it semipermeable •Thicker and faced is stronger and can have a lower perm rating •Considered a vapor retarder, not a vapor barrier •Absorbs more moisture than other insulation over the long term, and as a result its warranty doesn't honor R-value retention over the long haul	•Most often used in roofing applications •Average cost of 70¢ per sq. ft. for a 1-in.-thick panel (may vary based on region) •Standard R-Value of R 5.8 per inch •The manufacturing process starts with liquid foam •Not recyclable •Has to be sprayed against a substrate to form a rigid panel, so all ISO panels are faced •Different facings affect the performance of the panel in both durability and perm rating •Foil-faced panels are considered impermeable (because applying these products as sheathing creates an exterior vapor barrier, they never should be used with an interior vapor barrier) •More permeable panels are faced with fiberglass and can be used without creating a vapor barrier

3- Cellulose insulation: Cellulose insulation is created from recycled paper treated with fire-retardant chemicals. It is blown or densely packed into wall cavities and has high thermal performance, along with efficient soundproofing and fire protection.

Benefits:

1- The most obvious environmental benefit of cellulose insulation is that homeowners can reuse and recycle materials that would otherwise end up discarded in landfills

2- In terms of interior air quality, cellulose insulation has shallow VOC levels. A Healthy Building Science report finds that blown-in cellulose insulation has a total VOC (TVOC) level of under 101 µg/m3 and a total formaldehyde level of 12.7 µg/m3. This amount is significantly lower than what Greenguard certification requires for their low-VOC insulation products.

3- In general, cellulose insulation has a higher insulation capacity (R-value) than fiberglass. The Washington State University Energy Program reports that the R-value of loose-fill cellulose is R-3.2 to 3.8 per inch.

Type of Cellulose Insulation	R-Value
Loose-fill cellulose	Around 3.5 per inch of thickness
Dense-packed cellulose	Between 3.8 and 4.0
Wet-spray cellulose	3.6 to 3.8 per inch

Fig 3.12 Thickness of cellulose insulation

4- Fiberglass insulation: fiberglass batts or loose-fill insulation are widespread and economical solutions. While they have lower R-values compared to certain other materials, they can nevertheless provide adequate insulation when correctly constructed. Fiberglass is readily accessible and useful for both new construction and retrofitting old walls.

Pros of Fiberglass Insulation:

Fiberglass insulation is relatively quick and easy to install, mainly if you're working with professionals. It's also one of the most affordable ways of insulating a home, which is why it's such a popular option. Here are some of the advantages of insulating your home with fiberglass:

1- Flexibility: Fiberglass is available in pre-cut panels, rolls and loose-fill, making it incredibly flexible for installation. It can be placed between rafters, joists, blocks, studs, and any surface that needs insulation. Its flexibility makes fiberglass a very affordable option, particularly compared to similar insulation materials like spray foam.

2- Energy Efficient: On average, fiberglass insulation can help reduce heating and cooling bills by 40% to 50%. In addition to energy savings, fiberglass insulation can also help with noise reduction. Although fiberglass has a satisfactory R-value if it's not professionally installed, it can lose thermal protection over time.

3- Fire Retardant: Made from recycled glass and sand, fiberglass is a natural fire retardant that poses little to no fire hazard. There's also fiberglass material that's treated with a fire retardant to improve the level of safety.

4- Noise Cancelling: Fiberglass has natural sound-dampening properties that can significantly reduce noise coming into the house. Also known as acoustic insulation, fiberglass is used in walls, ceilings and even ducts to help reduce sound transfer.

5- Eco-Friendly: Made from recycled materials, fiberglass is an environmentally-friendly insulation alternative. Out of the most inexpensive insulation materials, fiberglass is one of the most eco-friendly, made of almost 30% recycled materials.

Cons of Fiberglass Insulation:

Despite its many advantages, homeowners considering fiberglass insulation need to pay close attention to its downsides. One of the most significant issues with fiberglass doesn't have to do with the product itself but with the installation. While it's an easy-to-install material, poor installation can lead to various problems down the line. Here are some other disadvantages of fiberglass insulation:

1- Coverage: Since most fiberglass panels come pre-cut, it's common to struggle with difficulties while installing them. Odd-shapes, crannies and other anomalies can present a challenge to standard-size fiberglass batts.

2- Air Exchange: Compared to other insulation materials, fiberglass is less dense and effective against air leaks. If you choose fiberglass installation, you need to factor in additional work to create an airtight seal. To prevent air exchange, other forms of insulation, such as sprayed foam, can be more efficient.

3- Moisture: In regions with high levels of humidity, fiberglass isn't as efficient at repelling moisture. Roof leaks and moisture in attics and basements can contaminate fiberglass insulation and lead to mold and mildew problems down the line. Much like with the airtight seal, an additional step is required to add a vapor barrier that keeps moisture away from the insulation material.

4- Mold: Because fiberglass can hold moisture, it easily creates a thriving environment for mold spores to settle. When mold occurs, the insulation needs to be replaced immediately to prevent further damage to the house's structure and walls.

Fiberglass Insulation R-Value by Type

Here is a breakdown of fiberglass insulation by type and the respective R-value.

Type of Insulation	R-Value
Batts	3.1 to 3.4 per inch of thickness
Loose-fill (attic)	2.2 to 4.3 per inch of thickness
Loose-fill (wall)	3.7 to 4.3 per inch of thickness
Rigid Fibrous	4 to 5 per inch of thickness

5- Mineral wool insulation: Mineral wool, often known as rock wool or slag wool, is manufactured from molten slag or natural rock elements. It is offered as batts, boards, or loose-fill insulation. Mineral wool provides high fire resistance, soundproofing qualities, and outstanding thermal performance.

- Typically, mineral or stone insulation contains up to 90% recycled content.

- In terms of thermal performance, mineral wool batts made for traditional 2×4 walls achieve an impressive R-value of 15. These R-values are significantly higher than the R-11 to R-13 values that characterize most fiberglass insulation batts.

- Mineral wool insulation can improve the energy efficiency of homes, helping to cut back on carbon emissions. The actual energy efficiency benefits will depend on the thickness of the walls and other building specifications. The R-value of 15 for 2x4 stud walls and R-23 for 2x6 stud walls is significantly better than the fiberglass' rating of R-11 or 13 and R-21, respectively. For this reason, mineral wool is an excellent choice for home renovations.

Fig 3.13 Rock wool insulation

6- VIPs (vacuum insulation panels) are high-performance insulation panels with exceptionally low thermal conductivity. They are made up of a core substance surrounded by a vacuum-sealed panel. While they have the greatest R-value per inch, they are somewhat pricey and may be better suited to certain applications or small spaces.

Fig 3.14 Vacuum insulation panel

Vacuum Insulation Panels are used in Buildings in order to improve building energy efficiency. Buildings account for a large fraction of total carbon emissions (40% of total energy use in the EU). Unfortunately, much space heating energy is lost through the poorly insulated building fabric of older buildings. Yet this problem also poses an opportunity for huge energy savings if such buildings can be retrofitted with adequate insulation.

As governments set aggressive goals with the aim of reducing the energy used to heat buildings, a major target is to lower the heat transfer coefficient (U-value) of the building fabric. VIPs are used in Buildings to make possible the retrofit of thermal barriers in older buildings, increasing energy efficiency where it might otherwise be impractical to accommodate thick layers of conventional insulation. The extremely low insulation thicknesses (10 mm to 25 mm) of VIPs makes them the perfect solution for retrofitting without compromising on the space. For new constructions, VIPs can be “built in” from the start. This integration allows for sleek designs that offer both space and energy savings.

3.1.3 Sustainable elements

Sustainability elements in the field of zero-energy building design are extensive and diverse. Based on the case studies we have previously seen, it encompasses all aspects of a building. However, the difference between starting from scratch with a zero-energy building and renovating an existing structure lies in the fact that in renovation, certain aspects of the building, such as its orientation, cannot be changed. The primary and initial foundation of the building must be preserved, and only modifications that do not alter the main structure's foundation are allowed. This point is crucial because it restricts the focus to a limited number of sustainability aspects, making it challenging to achieve a nearly zero-energy building. Below, you will find the main elements of sustainable buildings, along with a brief explanation:

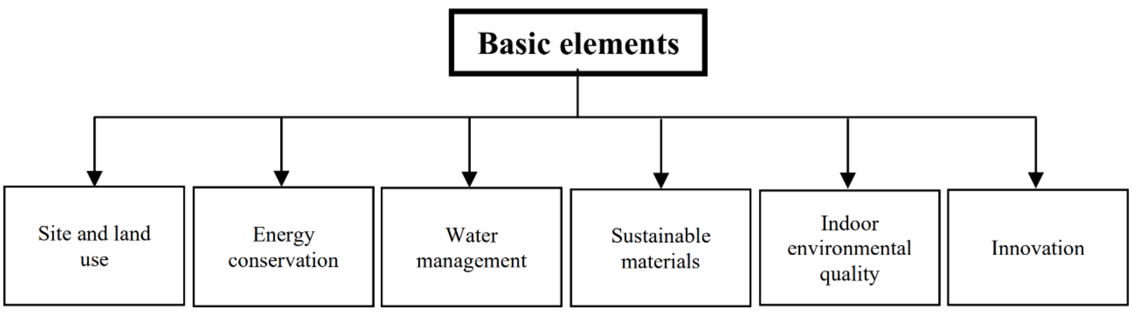


Fig 3.15 Sustainable elements for building

Site And Land Use:

Land is one of the most essential elements that support the life of human, animal and plant. Human activities can give significant impact to the environment and have to be strategized properly to support flora and fauna. It is important to choose the most suitable site and create a sustainable building planning to enhance the land use as well as improving the site surrounding. In the other hand, sustainable development must considering every single impact not only to the site development but the other areas which may contribute in creating a sustainable development project. .[15]

Energy Conservation:

Zero-energy building is not a realistic solution, but low-energy building design would be the most possible target to achieve in sustainable building design. Every building needs energy to operate, and effective energy management will be the best method for reducing the negative impact on the environment. At the same time, active and passive sustainable building elements should operate together, which may also depend on criteria such as climate, site location, social activities, economic issues, season, and building use. .[15]

Water Management:

Water is one of the important elements that contributes towards a sustainable building design. "Contemporary problems in water resources management andresources management in general, are characterized by increasing complexity (Claudia Pahl-Wolst et al, 2007)".The big issues related with this element include water treatment, minimizing water usage and waste water discharge should be considered. Both passive and active sustainable strategies can be applied simultaneously but still restricted to certain criteria. .[15]

Sustainable Materials:

Sustainable materials have a big impact on building design, from their aesthetic value to their cost and buildability. The impacts associated with materials on building design and the environment should be considered at an early stage in producing a sustainable building. Besides, the impact of the natural world should also be considered when creating a sustainable building material. "The natural world has an immense amount to tell us about how to achieve sustainability. It uses energy far more efficiently and effectively and is capable of producing materials and structures that are far more benign than anything we have achieved in industry (Godfaurd John et al., 2005)". All factors in choosing building materials, such as the manufacturing process, transport requirements, final disposal, and materials' resources, contribute to recognizing sustainable building materials. It is essential to know about the impacts of building materials, and one material’s assessment known as life cycle assessment (LCA) can evaluate the impact of construction elements on the environment. "Life Cycle Assessment (LCA) is the assessment of the impacts associated with materials from their resourcing and manufacturing to their disposal (Paola Sassi, 2011)." Unfortunately, some of the building materials' impacts on the building and environment cannot be detected due to certain issues, such as social issues and biodiversity. Designers should know how to select sustainable materials to protect the occupant from indoor pollution, such as indoor air pollution. "Indoor air pollution includes particulate matter from wood and coal smoke, as well as carbon monoxide and other unburnt hydrocarbons from wood, coal, and paraffin (Randal Spalding-Fecher, 2005)". [15]

Indoor Environmental Quality:

Indoor environmental quality is another essential factor in creating a sustainable building design. This factor can influence human health, which most of us do not realize. Deaths can happen due to the unhealthy indoor environment. Many kinds of development can affect our indoor environment, which can have a negative impact without being noticeable. .[15]

Innovation:

Innovation functioned as the complement element to create a sustainable building design. It would be an element to encourage people and professionals to apply a sustainable approach during the construction process as well as in their daily lives. Professionals, which consist of architects, engineers, surveyors, and others, are encouraged to implement a sustainable work environment as well as a positive strategy to attract people to be involved. The government will give certain advantages to a sustainable building project that implements sustainable work progress. It can educate all of the professionals, clients, contractors, and suppliers to implement a sustainable approach as part of their work style.[15]

3.1.4 Data analysis techniques

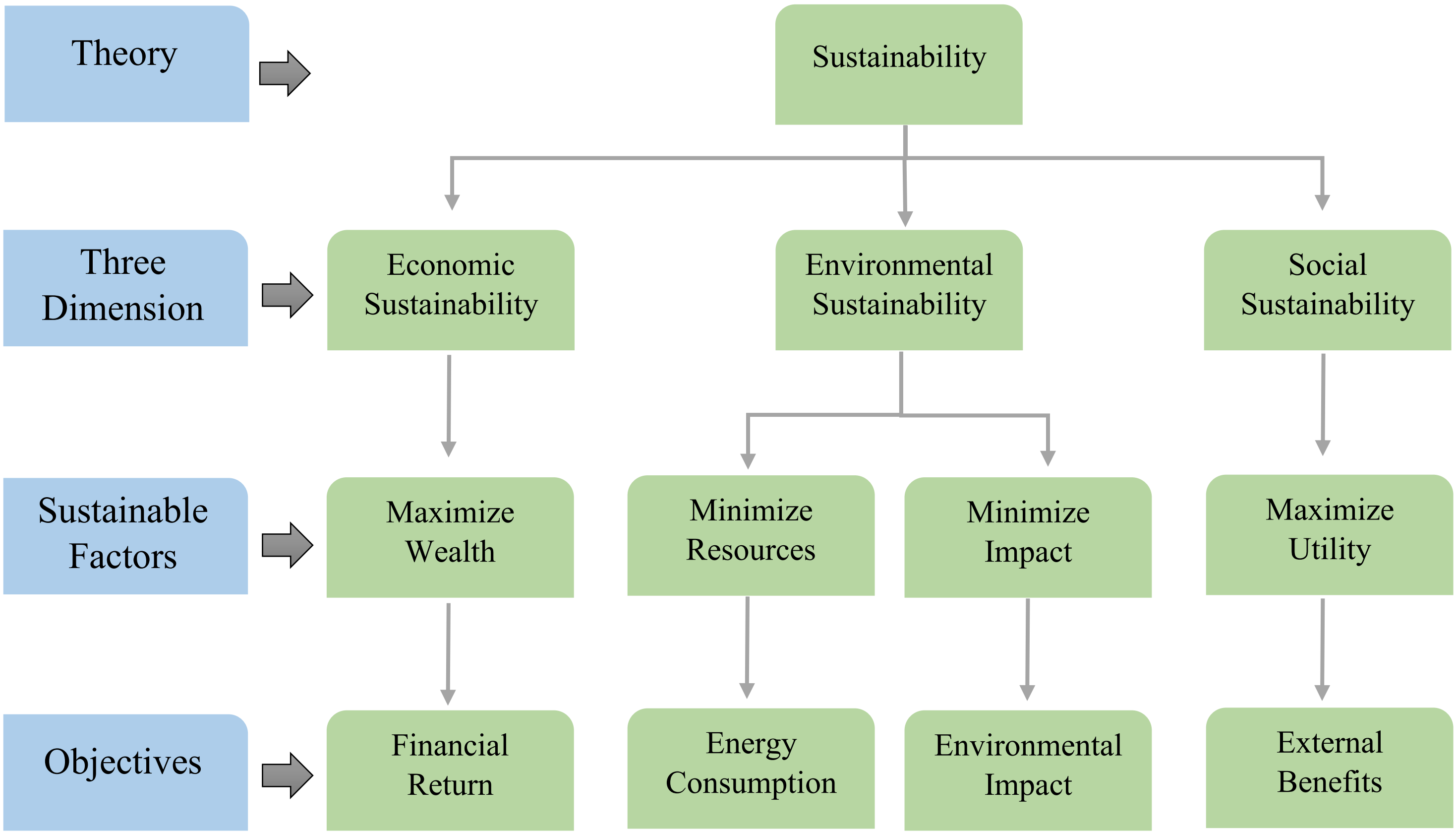


Fig 3.16 Concepts of sustainability from beginning to goals

Priority is given to the approach of assessing sustainability data based on building energy loads. The quantity of energy consumed by a building block is generally referred to as the building energy load. In essence, a building's energy requirements are determined by a variety of factors, and analyzing each of these aspects separately is a difficult undertaking. As a result, we only refer to one of these aspects, the type of materials used for walls, floors, and ceilings, while the others are treated as fixed characteristics.

Following that, we will explain these elements and offer a brief explanation of each factor's influence on the building's energy load.

The formula for calculating the building energy load is:

Energy Load (in kilowatt-hours, kWh) = Total Floor Area (in square meters, m^2) × Heating or Cooling Degree Days (HDD or CDD) × U-Value × Energy Conversion Factor

It should be noted that this formula has been simplified to its simplest form. With a deeper examination, each of these factors will be thoroughly investigated.

Let's break down the components of the formula:

- Total Floor Area: Measure the area of the building in square meters. It represents the total space that needs to be heated or cooled.

- Heating or Cooling Degree Days (HDD or CDD): Degree days are a measure of how much the average temperature departs from a baseline temperature over a specific period. HDD is used for heating load calculations, while CDD is used for cooling load calculations. You can obtain the degree day data from weather stations or online sources specific to your location.

Heating or Cooling Degree Days (HDD or CDD) are calculated to estimate the energy required for heating or cooling a building based on the difference between the outdoor temperature and a base temperature.

Determine Heating or Cooling Degree Days: To calculate Heating Degree Days (HDD) or Cooling Degree Days (CDD), sum the daily temperature differences over the desired period:

HDD = Σ (Daily Temperature Difference) for days when (Daily Temperature Difference) > 0

CDD = Σ (Daily Temperature Difference) for days when (Daily Temperature Difference) < 0

Σ: Represents the summation of the values.

- U-Value: The U-value, also known as the overall heat transfer coefficient, measures the rate of heat loss or gain through a building element (walls, roof, windows, etc.). It depends on the insulation properties of the materials used. Each building element will have its own U-value.

- Energy Conversion Factor: This factor converts the calculated load into kilowatt-hours (kWh). It accounts for various factors such as efficiency losses, heating or cooling system performance, and conversion factors from other energy units.

The Energy Conversion Factor is calculated by multiplying the energy content by the conversion efficiency. You may need to convert the energy content and efficiency units to a common basis, such as joules or kilowatt-hours, before performing the calculation. The formula is:

ECF = Energy Content × Conversion Efficiency

Energy Content: The energy content of the fuel type (in joules, BTUs, or kWh per unit of fuel).

The energy content value for electricity is typically measured in kilowatt-hours (kWh) per unit of consumption. For example, if 1 kWh of electricity is consumed, it represents 3,600,000 joules (or 3.6 megajoules) of energy.

Conversion Efficiency: The conversion efficiency of the fuel type (expressed as a decimal or percentage).

To calculate the energy load for a specific fuel type, multiply the fuel consumption by the corresponding Energy Conversion Factor. This converts the fuel consumption into a common energy unit for consistent energy load calculations.

Energy Load (in common energy unit) = Fuel Consumption (in fuel-specific units) × ECF

Fuel Consumption: The consumption of the specific fuel type (in units such as kilowatt-hours, cubic meters, gallons, or kilograms).

ECF: The Energy Conversion Factor for the fuel type (in common energy unit per unit of fuel).

In Italy, the conversion efficiency for electricity can vary based on several factors, including the generation technology and the specific regulations in place. However, a commonly used conversion efficiency for electricity in Italy is around 0.33 or 33%.

It's important to note that the conversion efficiency for electricity can vary depending on the specific generation technologies employed.

- Occupancy Schedule: Take into account the occupancy schedule of the building. Consider the number of occupants, their activities, and the corresponding heat gain or loss during different periods of the day.

- Internal Heat Gain: Account for internal heat sources such as lighting, appliances, and equipment within the building. These contribute to the overall heat load and can vary based on the type and usage patterns of the equipment.

- Infiltration and Ventilation: Include the effect of air infiltration and ventilation rates on the building's energy load. Proper ventilation is necessary for indoor air quality, but it can also result in additional heating or cooling requirements.

- Solar Heat Gain: Consider the solar heat gain through windows and other building openings. The orientation and shading of the building, as well as the properties of the glazing, can impact the amount of solar radiation entering the building.

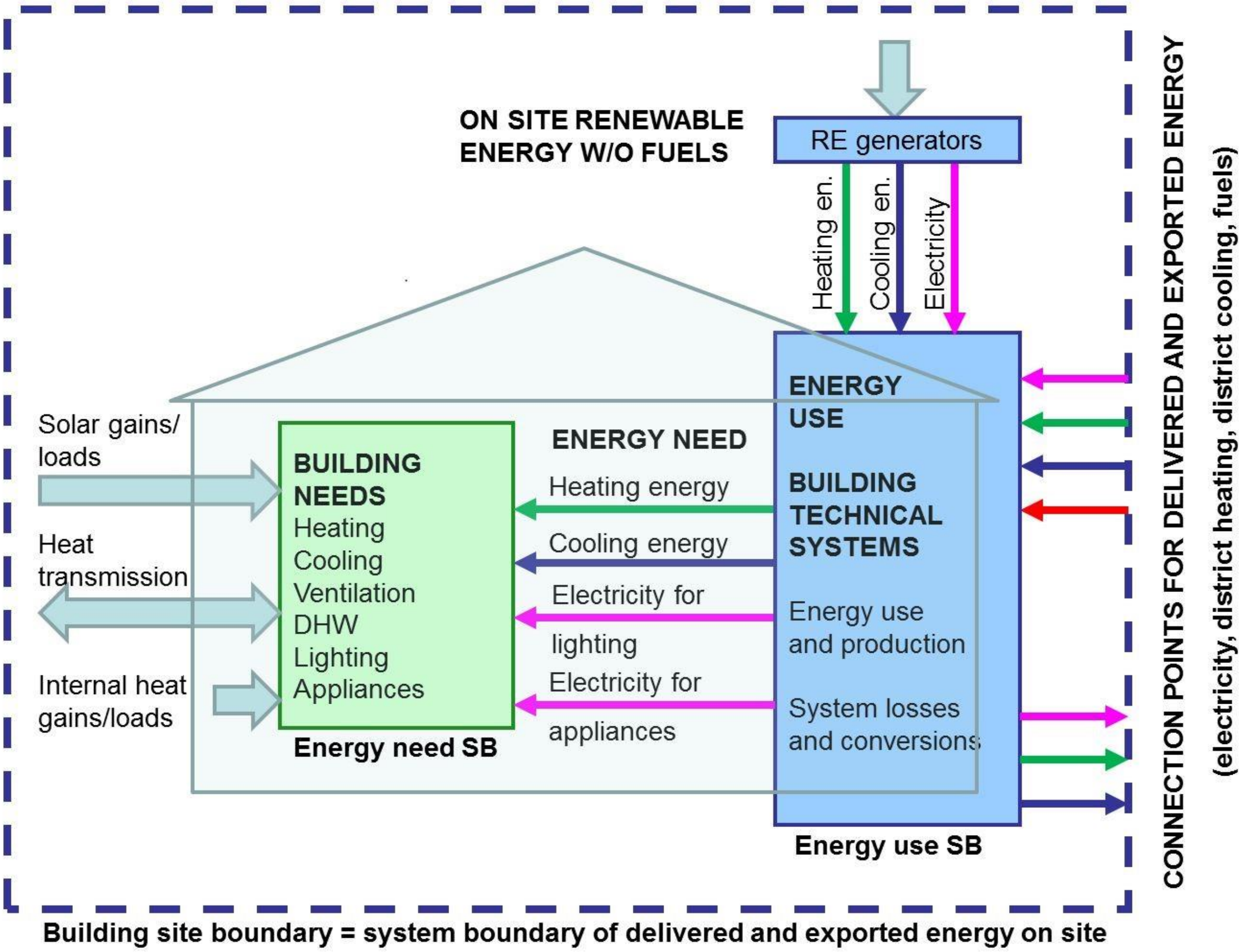


Fig 3.17 A variety of sustainable elements that can be used in the building

- Thermal Mass: Take into account the thermal mass of the building materials. Materials with high thermal mass can help absorb and store heat, affecting the heating and cooling loads.

- Equipment Efficiency: Incorporate the efficiency ratings of HVAC (Heating, Ventilation, and Air Conditioning) systems, lighting fixtures, and other equipment used in the building. Higher efficiency equipment will result in lower energy loads.

- Renewable Energy Sources: If the building utilizes renewable energy sources such as solar panels or geothermal systems, consider their contribution to offsetting the energy load.

As we can observe, there are too many factors have impacts on the building energy load. To calculate the energy load of our building, we have to consider these factors by defining the usage of each one. As I already mention that, we only focused on the material of the walls and floors and the effect of these materials on the energy load of a building during a renovation.

The thermal qualities of the materials used must be considered when calculating the influence of wall materials on the energy load of a building. The thermal conductivity, commonly known as the U-value or the heat transfer coefficient, is an important metric to consider since it measures the rate of heat transmission through a material.

1- Determine the U-value of the wall: The U-value represents the overall heat transfer coefficient of the wall, taking into account the individual layers and their respective thermal conductivities. Each layer of the wall, such as insulation, drywall, and exterior cladding, will contribute to the U-value.

2- Calculate the thermal resistance (R-value): The thermal resistance represents the ability of a material or assembly to resist heat flow. It is the reciprocal of the U-value. You can calculate the R-value by taking the inverse of the U-value: R-value = 1 / U-value.

3- Determine the surface area of the walls: Measure the surface area of the walls that are exposed to the exterior or conditioned spaces. This will depend on the building's floor plan and the height of the walls.

4- Calculate the conductive heat transfer: The conductive heat transfer through the walls can be calculated using the formula:

Heat Transfer (in watts, W) = U-value (in watts per square meter per degree Celsius, $W/m^2 °C$) × Surface Area (in square meters, m^2) × Temperature Difference (in degrees Celsius, °C)

The temperature difference is the indoor temperature minus the outdoor temperature. If you're calculating the heating load, it's the difference between the desired indoor temperature and the outdoor temperature. If you're calculating the cooling load, it's the difference between the outdoor temperature and the desired indoor temperature.

5- Convert the heat transfer to the energy load: To convert the heat transfer in watts to the energy load in kilowatt-hours (kWh), you need to consider the time factor. Multiply the heat transfer by the time (in hours) for which the load is applicable and divide by 1,000 to convert it to kWh:

Energy Load (in kWh) = (Heat Transfer × Time) / 1000

By incorporating the U-value and surface area of the walls into the energy load calculation, you can assess the impact of different wall materials on the building's overall energy load. Remember to consider the thermal properties of other building elements as well, such as windows, roof, and floors, for a comprehensive analysis.

3.2 Analysis and Energy Result

3.2.1 Energy Load Calculation:

In the context of energy analysis and the impact of sustainability on a building, one of the influential factors is the energy load of the building. Essentially, the energy load represents the amount of energy that a building requires and consumes over a specific period of time. Consequently, it is a critical factor in energy analysis. A lower energy load value for a building corresponds to reduced energy consumption, resulting in less environmental impact. A critical feature of modern construction and design is the link between building energy loads and sustainable building techniques. Sustainable buildings are designed to have a low environmental impact, improve energy efficiency, and offer residents a healthy and comfortable indoor environment. The quantity of energy necessary to maintain a certain level of comfort and functioning within a structure, referred to as the building energy load, plays a crucial role in accomplishing these sustainability goals.

A key element of sustainable building design is reducing the energy burden of the structure. Sustainable buildings attempt to reduce their dependency on non-renewable energy and greenhouse gas emissions by installing energy-efficient measures and employing renewable energy sources. This not only aids in the fight against climate change but also cuts total energy usage and operational costs for buildings.

Several ways may be used to lower the energy load of a building and improve its sustainability:

1- Energy-Efficient Building Envelope: Using high-performance windows, adequate sealing, and insulation materials to design and create a well-insulated building envelope helps minimize heat transfer and air leakage. As a result, the heating and cooling loads are reduced, resulting in decreased energy consumption.

2- Efficient HVAC Systems: Choosing and implementing energy-efficient heating, ventilation, and air conditioning (HVAC) systems cuts energy usage dramatically. Heat pumps, energy recovery ventilation, and smart controls are examples of technology that may be used to enhance HVAC operations and increase overall system efficiency.

3- Lighting Efficiency: Using energy-efficient lighting systems, such as LED lighting and daylight harvesting techniques, can help minimize electricity use for lighting. This may be accomplished through the use of energy-efficient fixtures, automated controls, and natural lighting design.

4- Renewable Energy Integration: Buildings may create clean, sustainable energy on-site by incorporating renewable energy sources such as solar panels or wind turbines. This lessens the building's reliance on fossil fuels while also lowering its environmental impact.

5- Occupant Behavior and Education: Developing energy-conscious behavior among occupants through awareness campaigns and education aids in energy use optimization. Encouraging energy-saving habits like turning off lights when not in use, lowering thermostat settings, and installing energy-efficient equipment all help to reduce the building's energy burden.

The goal of sustainable construction methods is to strike a balance between environmental, social, and economic concerns. Sustainable buildings contribute to resource conservation, greenhouse gas reduction, and long-term cost savings by decreasing building energy loads through energy-efficient design, construction, and operating measures. These practices fit with global sustainability goals, improve occupant comfort and well-being, and indicate a commitment to responsible and ecologically conscientious building design and operation.

The topic of energy load is extensive, and delving into all its aspects with accuracy and scientific rigor is necessary to ensure reliable results. It is incorrect and impractical to cover all aspects of energy load in this discussion. To ensure precision in the obtained results, one important factor, namely the material of the walls and, more generally, the building's external and internal envelope, has been examined. It is important to note that other influential factors have also been considered in the calculations. However, their coefficients have been treated as constant values, and the average load for an office building in Turin, Italy, has been substituted in their place in the main equation. It is explicitly stated for each factor that a constant value has been utilized.

The main formula for the energy load calculation would be:

Energy Load = Heating Load + Cooling Load + Ventilation Load + Lighting Load + Equipment Load

1- Heating Load: This accounts for the energy required to maintain the desired indoor temperature during colder periods. It considers factors such as outdoor temperature, building insulation, and heat loss through walls, windows, and roofs.

Heating Load = (Area × U-Value × Temperature Difference) + Infiltration Load + Ventilation Load + Internal Heat Gains

2- Cooling Load: This represents the energy required to cool the building during warmer periods. It takes into account factors such as outdoor temperature, solar radiation, building envelope characteristics, and internal heat gains.

Cooling Load = (Area × U-Value × Temperature Difference) + Solar Heat Gain + Internal Heat Gains

3- Ventilation Load: This accounts for the energy needed to supply fresh air to the building for maintaining indoor air quality. It considers factors such as the number of occupants, building size, ventilation rates, and outdoor air conditions.

Ventilation Load = Ventilation Rate × Specific Heat Capacity × Temperature Difference

4- Lighting Load: This represents the energy consumption of lighting systems within the building. It depends on the type and number of light fixtures, lamp types, wattages, and hours of operation.

Lighting Load = (Number of Light Fixtures × Power per Fixture) × Hours of Operation

5- Equipment Load: This refers to the energy consumption of various electrical equipment in the building, such as computers, appliances, machinery, and other devices. It depends on the power rating, usage patterns, and operating hours of the equipment.

Equipment Load = (Number of Equipment × Power per Equipment) × Hours of Operation

In our scenario, we have to consider the most important factors for the energy load of a building, which would be the heating load and the cooling load. They had a direct influence on increasing or decreasing the energy load level, and their impact can develop the energy efficiency of buildings. So focusing on them is prior in this thesis. Factor by factor going forward to check each item to achieve the goals.

<Wall Material Takeoff>							
A	B	C	D	E	F	G	H
Material: Name	Material: Area	Width	Length	Thermal Mass	Thermal Resistance	Base Constraint	Top Constraint
Air	442.02 m^2	0.52 m	74.81 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Air	113.87 m^2	0.52 m	22.28 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Air	38.16 m^2	0.22 m	5.97 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Air	42.82 m^2	0.22 m	6.16 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Air	25.38 m^2	0.52 m	4.84 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Air	690.09 m^2	0.22 m	28.93 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: Top Height
Air	293.98 m^2	0.22 m	12.50 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: Top Height
Air	275.92 m^2	0.52 m	12.38 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: Top Height
Air	858.72 m^2	0.61 m	36.47 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Air	265.54 m^2	0.61 m	11.29 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Air	837.32 m^2	0.61 m	36.02 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Air	54.81 m^2	0.22 m	7.48 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Air	31.35 m^2	0.22 m	2.01 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Air	6.38 m^2	0.22 m	0.62 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Air	168.29 m^2	0.22 m	32.23 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Roof
Air	17.15 m^2	0.52 m	2.01 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Air	552.73 m^2	0.22 m	32.30 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Roof
Air	20.19 m^2	0.22 m	1.30 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Air	11.50 m^2	0.52 m	0.74 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Air	681.64 m^2	0.52 m	40.51 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Air	63.85 m^2	0.52 m	32.30 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	Roof	Up to level: Top Height
Air	64.46 m^2	0.52 m	32.59 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	Roof	Up to level: Top Height
Air: 22	5556.16 m^2						
Brick, Common	112.54 m^2	0.12 m	33.47 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	5.05 m^2	0.12 m	1.21 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	12.99 m^2	0.12 m	3.74 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	24.91 m^2	0.12 m	6.24 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	22.86 m^2	0.12 m	7.03 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	23.19 m^2	0.12 m	6.42 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	12.56 m^2	0.12 m	3.72 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	14.19 m^2	0.12 m	4.05 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	14.19 m^2	0.12 m	4.05 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	14.19 m^2	0.12 m	4.05 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	13.42 m^2	0.12 m	3.79 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	14.19 m^2	0.12 m	4.05 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	14.19 m^2	0.12 m	4.05 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	22.48 m^2	0.12 m	6.24 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	11.54 m^2	0.12 m	3.59 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	21.52 m^2	0.12 m	6.29 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	23.44 m^2	0.12 m	6.29 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	15.27 m^2	0.12 m	4.14 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	23.19 m^2	0.12 m	6.42 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	23.19 m^2	0.12 m	6.42 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	23.12 m^2	0.12 m	6.14 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	23.06 m^2	0.12 m	6.13 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	8.97 m^2	0.12 m	2.92 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	5.18 m^2	0.12 m	2.36 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	12.55 m^2	0.12 m	3.50 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	6.84 m^2	0.12 m	2.36 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	7.20 m^2	0.12 m	2.21 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	4.58 m^2	0.12 m	1.76 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	3.17 m^2	0.12 m	1.39 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	3.16 m^2	0.12 m	1.62 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	68.15 m^2	0.12 m	20.34 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	4.86 m^2	0.12 m	2.07 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Brick, Common	111.63 m^2	0.12 m	34.24 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	28.13 m^2	0.12 m	8.58 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	24.83 m^2	0.12 m	6.58 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	39.86 m^2	0.12 m	12.00 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	24.37 m^2	0.12 m	6.58 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	13.31 m^2	0.12 m	4.53 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	1.16 m^2	0.12 m	0.31 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	38.97 m^2	0.12 m	11.89 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	44.29 m^2	0.12 m	12.44 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	17.03 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	18.95 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	18.95 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	18.95 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	18.95 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	18.95 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	18.95 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	24.09 m^2	0.12 m	6.51 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	24.09 m^2	0.12 m	6.51 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	22.93 m^2	0.12 m	6.20 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	24.37 m^2	0.12 m	6.58 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	24.37 m^2	0.12 m	6.58 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	7.22 m^2	0.12 m	1.90 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	2.60 m^2	0.12 m	0.69 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	15.71 m^2	0.12 m	4.30 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	10.88 m^2	0.12 m	4.42 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common	9.51 m^2	0.12 m	2.67 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Brick, Common: 58	1232.98 m^2						
Concrete Masonry Units	442.02 m^2	0.52 m	74.81 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Concrete Masonry Units	113.87 m^2	0.52 m	22.28 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Concrete Masonry Units	38.16 m^2	0.22 m	5.97 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Concrete Masonry Units	42.82 m^2	0.22 m	6.16 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Concrete Masonry Units	25.38 m^2	0.52 m	4.84 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Concrete Masonry Units	690.09 m^2	0.22 m	28.93 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: Top Height
Concrete Masonry Units	293.98 m^2	0.22 m	12.50 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: Top Height
Concrete Masonry Units	275.92 m^2	0.52 m	12.38 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: Top Height
Concrete Masonry Units	858.72 m^2	0.61 m	36.47 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Concrete Masonry Units	265.54 m^2	0.61 m	11.29 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Concrete Masonry Units	837.32 m^2	0.61 m	36.02 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Concrete Masonry Units	54.81 m^2	0.22 m	7.48 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Concrete Masonry Units	31.35 m^2	0.22 m	2.01 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Concrete Masonry Units	6.38 m^2	0.22 m	0.62 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Concrete Masonry Units	168.29 m^2	0.22 m	32.23 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Roof
Concrete Masonry Units	17.15 m^2	0.52 m	2.01 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Concrete Masonry Units	552.73 m^2	0.22 m	32.30 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Roof
Concrete Masonry Units	20.19 m^2	0.22 m	1.30 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Concrete Masonry Units	14.65 m^2	0.52 m	0.74 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Concrete Masonry Units	681.64 m^2	0.52 m	40.51 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Concrete Masonry Units	63.85 m^2	0.52 m	32.30 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	Roof	Up to level: Top Height
Concrete Masonry Units	64.46 m^2	0.52 m	32.59 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	Roof	Up to level: Top Height
Concrete Masonry Units: 22	5559.31 m^2						
Default Wall	19.38 m^2	0.30 m	4.20 m			Ground Floor	Up to level: First Floor
Default Wall: 1	19.38 m^2						
Fiberglass insulation	442.02 m^2	0.52 m	74.81 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Fiberglass insulation	113.87 m^2	0.52 m	22.28 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Fiberglass insulation	38.16 m^2	0.22 m	5.97 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Fiberglass insulation	42.82 m^2	0.22 m	6.16 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Fiberglass insulation	25.38 m^2	0.52 m	4.84 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Fiberglass insulation	690.09 m^2	0.22 m	28.93 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: Top Height
Fiberglass insulation	293.98 m^2	0.22 m	12.50 m	[illegible]	[illegible]	0.0	Up to level: Top Height
Fiberglass insulation	275.92 m^2	0.52 m	12.38 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: Top Height
Fiberglass insulation	858.72 m^2	0.61 m	36.47 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Fiberglass insulation	265.54 m^2	0.61 m	11.29 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Fiberglass insulation	837.32 m^2	0.61 m	36.02 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Fiberglass insulation	54.81 m^2	0.22 m	7.48 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Fiberglass insulation	31.35 m^2	0.22 m	2.01 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Fiberglass insulation	6.38 m^2	0.22 m	0.62 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Fiberglass insulation	168.29 m^2	0.22 m	32.23 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Roof
Fiberglass insulation	17.15 m^2	0.52 m	2.01 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Fiberglass insulation	552.73 m^2	0.22 m	32.30 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Roof
Fiberglass insulation	20.19 m^2	0.22 m	1.30 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Fiberglass insulation	14.88 m^2	0.52 m	0.74 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Fiberglass insulation	681.64 m^2	0.52 m	40.51 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Fiberglass insulation	63.85 m^2	0.52 m	32.30 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	Roof	Up to level: Top Height
Fiberglass insulation	64.46 m^2	0.52 m	32.59 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	Roof	Up to level: Top Height
Fiberglass insulation: 22	5559.54 m^2						
Gypsum Wall Board	442.02 m^2	0.52 m	74.81 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Gypsum Wall Board	113.87 m^2	0.52 m	22.28 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Gypsum Wall Board	38.16 m^2	0.22 m	5.97 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Gypsum Wall Board	42.82 m^2	0.22 m	6.16 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Gypsum Wall Board	25.38 m^2	0.52 m	4.84 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
Gypsum Wall Board	690.09 m^2	0.22 m	28.93 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: Top Height
Gypsum Wall Board	293.98 m^2	0.22 m	12.50 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: Top Height
Gypsum Wall Board	275.92 m^2	0.52 m	12.38 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: Top Height
Gypsum Wall Board	858.72 m^2	0.61 m	36.47 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Gypsum Wall Board	265.54 m^2	0.61 m	11.29 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Gypsum Wall Board	837.32 m^2	0.61 m	36.02 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
Gypsum Wall Board	54.81 m^2	0.22 m	7.48 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
Gypsum Wall Board	31.35 m^2	0.22 m	2.01 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Gypsum Wall Board	6.38 m^2	0.22 m	0.62 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Gypsum Wall Board	168.29 m^2	0.22 m	32.23 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Roof
Gypsum Wall Board	17.15 m^2	0.52 m	2.01 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Gypsum Wall Board	552.73 m^2	0.22 m	32.30 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Roof
Gypsum Wall Board	20.19 m^2	0.22 m	1.30 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
Gypsum Wall Board	15.03 m^2	0.52 m	0.74 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Gypsum Wall Board	681.64 m^2	0.52 m	40.51 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
Gypsum Wall Board	63.85 m^2	0.52 m	32.30 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	Roof	Up to level: Top Height
Gypsum Wall Board	64.46 m^2	0.52 m	32.59 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	Roof	Up to level: Top Height
Gypsum Wall Board: 22	5559.69 m^2						
lucerna stone	442.02 m^2	0.52 m	74.81 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
lucerna stone	113.87 m^2	0.52 m	22.28 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
lucerna stone	38.16 m^2	0.22 m	5.97 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
lucerna stone	42.82 m^2	0.22 m	6.16 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
lucerna stone	25.38 m^2	0.52 m	4.84 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: First Floor
lucerna stone	690.09 m^2	0.22 m	28.93 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: Top Height
lucerna stone	293.98 m^2	0.22 m	12.50 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: Top Height
lucerna stone	275.92 m^2	0.52 m	12.38 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	0.0	Up to level: Top Height
lucerna stone	858.72 m^2	0.61 m	36.47 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
lucerna stone	265.54 m^2	0.61 m	11.29 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
lucerna stone	837.32 m^2	0.61 m	36.02 m	804.74 kJ/(m^2·K)	1.2308 (m^2·K)/W	0.0	Up to level: Top Height
lucerna stone	54.81 m^2	0.22 m	7.48 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	0.0	Up to level: First Floor
lucerna stone	31.35 m^2	0.22 m	2.01 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
lucerna stone	6.38 m^2	0.22 m	0.62 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
lucerna stone	168.29 m^2	0.22 m	32.23 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Roof
lucerna stone	17.15 m^2	0.52 m	2.01 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
lucerna stone	552.73 m^2	0.22 m	32.30 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Roof
lucerna stone	20.19 m^2	0.22 m	1.30 m	215.06 kJ/(m^2·K)	0.9308 (m^2·K)/W	First Floor	Up to level: Top Height
lucerna stone	11.35 m^2	0.52 m	0.74 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
lucerna stone	681.64 m^2	0.52 m	40.51 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	First Floor	Up to level: Top Height
lucerna stone	63.85 m^2	0.52 m	32.30 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	Roof	Up to level: Top Height
lucerna stone	64.46 m^2	0.52 m	32.59 m	653.54 kJ/(m^2·K)	1.1538 (m^2·K)/W	Roof	Up to level: Top Height
lucerna stone: 22	5556.01 m^2						
Plaster	225.08 m^2	0.12 m	33.47 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	10.11 m^2	0.12 m	1.21 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	25.99 m^2	0.12 m	3.74 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	49.82 m^2	0.12 m	6.24 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	45.71 m^2	0.12 m	7.03 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	28.38 m^2	0.12 m	4.05 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	28.38 m^2	0.12 m	4.05 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	28.38 m^2	0.12 m	4.05 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	26.83 m^2	0.12 m	3.79 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	28.38 m^2	0.12 m	4.05 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	28.38 m^2	0.12 m	4.05 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	44.96 m^2	0.12 m	6.24 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	23.08 m^2	0.12 m	3.59 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	43.04 m^2	0.12 m	6.29 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	46.88 m^2	0.12 m	6.29 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	30.54 m^2	0.12 m	4.14 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	46.37 m^2	0.12 m	6.42 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	46.37 m^2	0.12 m	6.42 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	46.24 m^2	0.12 m	6.14 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	46.12 m^2	0.12 m	6.13 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	17.95 m^2	0.12 m	2.92 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	10.35 m^2	0.12 m	2.36 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	25.09 m^2	0.12 m	3.50 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	13.68 m^2	0.12 m	2.36 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	14.40 m^2	0.12 m	2.21 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	9.16 m^2	0.12 m	1.76 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	6.35 m^2	0.12 m	1.39 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	6.32 m^2	0.12 m	1.62 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	136.31 m^2	0.12 m	20.34 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	9.71 m^2	0.12 m	2.07 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	Ground Floor	Up to level: First Floor
Plaster	223.27 m^2	0.12 m	34.24 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	56.27 m^2	0.12 m	8.58 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	49.65 m^2	0.12 m	6.58 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	79.71 m^2	0.12 m	12.00 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	48.74 m^2	0.12 m	6.58 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	26.62 m^2	0.12 m	4.53 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	2.32 m^2	0.12 m	0.31 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	77.93 m^2	0.12 m	11.89 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	88.59 m^2	0.12 m	12.44 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	34.06 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	37.90 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	37.90 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	37.90 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	37.90 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	37.90 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	37.90 m^2	0.12 m	5.16 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	48.17 m^2	0.12 m	6.51 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	48.17 m^2	0.12 m	6.51 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	45.85 m^2	0.12 m	6.20 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	48.74 m^2	0.12 m	6.58 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	48.74 m^2	0.12 m	6.58 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	14.44 m^2	0.12 m	1.90 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	5.21 m^2	0.12 m	0.69 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	31.41 m^2	0.12 m	4.30 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	21.77 m^2	0.12 m	4.42 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster	19.02 m^2	0.12 m	2.67 m	143.22 kJ/(m^2·K)	0.2037 (m^2·K)/W	First Floor	Up to level: Second Floor
Plaster: 58	2465.96 m^2						

Table 3.5 Wall Material takeoff (Current building)

Wall Material Takeoff represents an optimal solution for obtaining comprehensive and relevant information about the various types of materials employed in the construction of our buildings. The provided table elucidates, through a simplified examination, the quantitative values of volume, length, width, thermal Mass, and thermal resistance associated with each material. Leveraging these data in energy calculations for building designs proves to be of significant assistance. This particular attribute further accentuates the advantages and practicality of utilizing Wall Material Takeoff in construction and related domains.

Ground Floor	Wall 1	Wall 2	Wall 3
Area	133.09 (m^2)	49.12 (m^2)	86 (m^2)
Windows	51 (m^2)	6 (m^2)	32.5 (m^2)
Wall (net)	82.09 (m^2)	43.12 (m^2)	53.50 (m^2)
Wall (U-value)	0.019 (W/m^2K)	0.019 (W/m^2K)	0.019 (W/m^2K)
Window (U-value)	17.28 (W/m^2K)	2.16 (W/m^2K)	10.8 (W/m^2K)

First Floor	Wall 1	Wall 2	Wall 3
Area	133.09 (m^2)	49.12 (m^2)	133.09 (m^2)
Windows	62 (m^2)	6 (m^2)	62 (m^2)
Wall (net)	71.09 (m^2)	43.12 (m^2)	71.09 (m^2)
Wall (U-value)	0.019 (W/m^2K)	0.019 (W/m^2K)	0.019 (W/m^2K)
Window (U-value)	17.28 (W/m^2K)	2.16 (W/m^2K)	10.8 (W/m^2K)

U-value calculation of the building:

At the first step we have to consider the 2 phases of the building. First the current situation of the project and the next phase would be the designing project. Below there are calculation of the current walls , floors and the windows of the Polito's building.

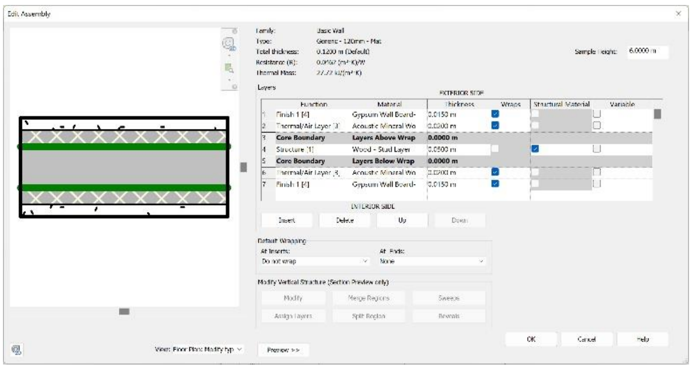


Fig 3.18 Internal wall layers – Current situation

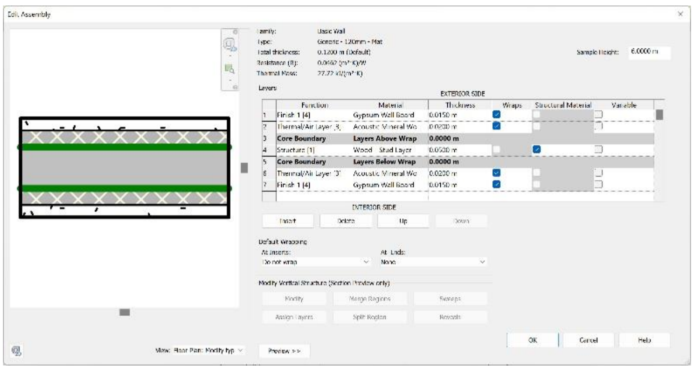
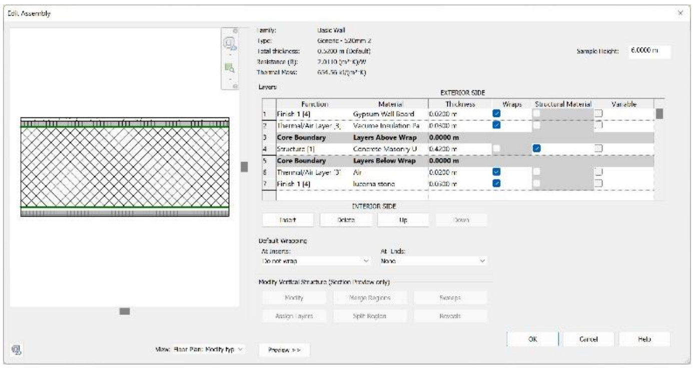


Fig 3.19 Internal wall layers – Project situation



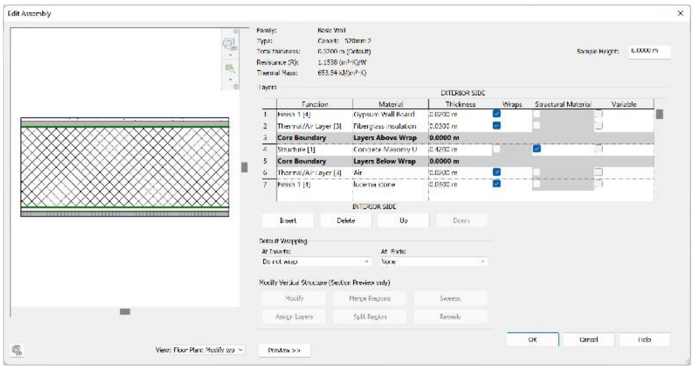


Fig 3.20 External wall layers – Current situation

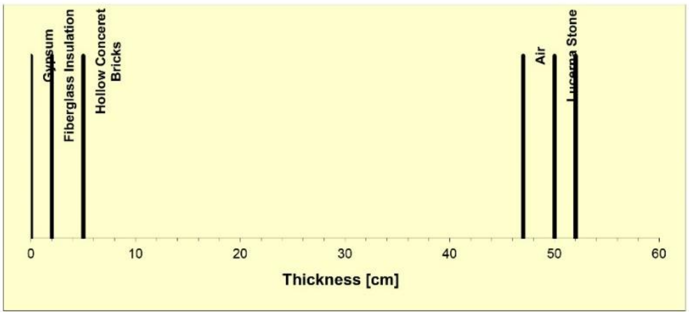
Fig 3.21 External wall layer – Project situation

Type of component	External wall

Layers (int-est)		d [cm]	ρ [kg/m³]	μ [-]	c [J/kg°C]	λ [W/m°C]	R [m²°C/W]	opz. λ→R
Internal surface							0.13	
I	Gypsum	2.0	1100	5	1100	0.180		☐
II	Fiberglass Insulation	3.0	30	15	950	0.003		☐
III	Hollow Conceret Bric	42.0	1800	50	1000	0.010		☐
IV	Air	3.0	1	1	1000	0.190		☐
V	Lucerna Stone	2.0	2600	10	900	2.500		☐
VI								☐
VII								☐
VIII								☐
IX								☐
X								☐
External surface							0.04	

Parameter	Module	Time shift
Internal thermal admittance (Y_{ii})	1.683 W/(m²K)	4.71 h
External thermal admittance (Y_{ee})	3.911 W/(m²K)	4.63 h
Periodic thermal transmittance (Y_{ie})	0.000 W/(m²K)	11.68 h
Internal areal heat capacity (κ_i)	23.1 kJ/(m²K)	
External areal heat capacity (κ_e)	53.8 kJ/(m²K)	
Thermal resistance (R)	52.447 (m²K)/W	
Thermal transmittance (U)	0.019 W/(m²K)	
Decrement factor (f)	0.000	

Thickness (s)	52.0 cm	
Areal mass (m)	831 kg/m²	
Time lag (φ)	12.32 h	



LEGENDA
d = thickness
ρ = density
μ = water vapour resistance factor
c = specific heat capacity
λ = thermal conductivity
R = thermal resistance

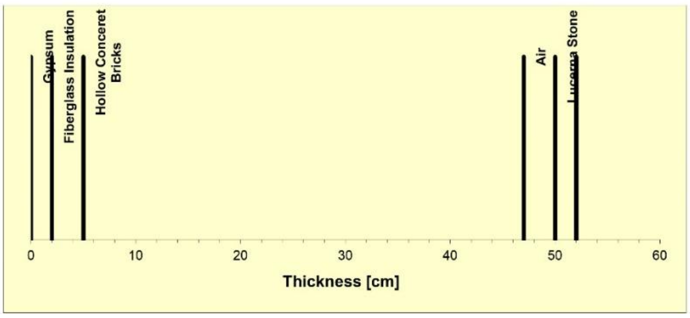
Fig 3.22 Wall 1-2-3-7 U-value Calculation

Type of component	External wall

Layers (int-est)		d [cm]	ρ [kg/m³]	μ [-]	c [J/kg°C]	λ [W/m°C]	R [m²°C/W]	opz. λ→R
Internal surface							0.13	
I	Gypsum	2.0	1100	5	1100	0.180		☐
II	Fiberglass Insulation	3.0	30	15	950	0.003		☐
III	Hollow Conceret Bric	42.0	1800	50	1000	0.010		☐
IV	Air	3.0	1	1	1000	0.190		☐
V	Lucerna Stone	2.0	2600	10	900	2.500		☐
VI								☐
VII								☐
VIII								☐
IX								☐
X								☐
External surface							0.04	

Parameter	Module	Time shift
Internal thermal admittance (Y_{ii})	1.683 W/(m²K)	4.71 h
External thermal admittance (Y_{ee})	3.911 W/(m²K)	4.63 h
Periodic thermal transmittance (Y_{ie})	0.000 W/(m²K)	11.68 h
Internal areal heat capacity (κ_i)	23.1 kJ/(m²K)	
External areal heat capacity (κ_e)	53.8 kJ/(m²K)	
Thermal resistance (R)	52.447 (m²K)/W	
Thermal transmittance (U)	0.019 W/(m²K)	
Decrement factor (f)	0.000	

Thickness (s)	52.0 cm	
Areal mass (m)	831 kg/m²	
Time lag (φ)	12.32 h	



LEGENDA
d = thickness
ρ = density
μ = water vapour resistance factor
c = specific heat capacity
λ = thermal conductivity
R = thermal resistance

Fig 3.23 Walls 4-5-6 U-value Calculation

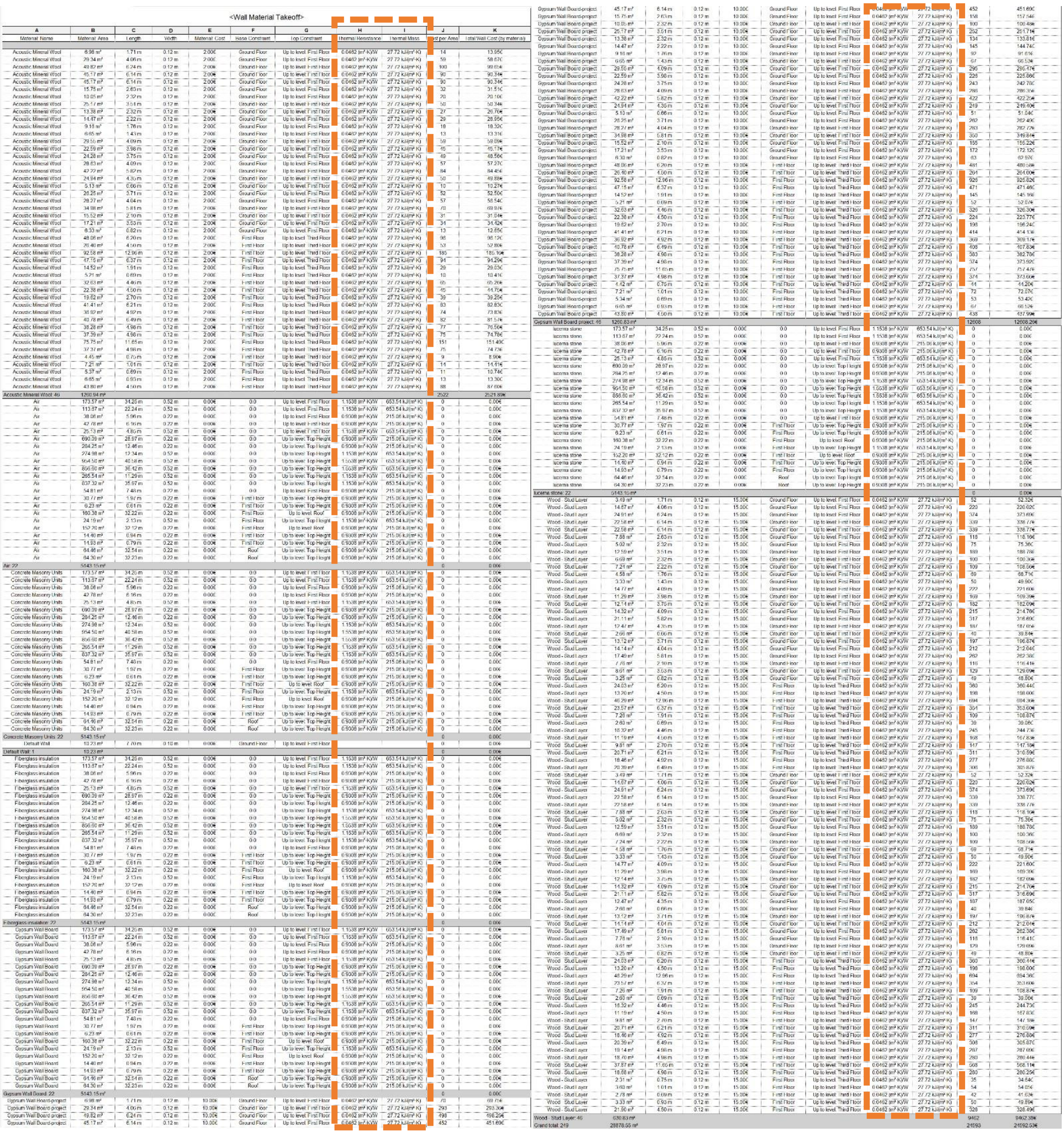


Table 3.5 Wall Material Takeoff (Project)

fixes values

R_{se} [m²K/W]	0.04	T_m [K]	283.15
R_{si} [m²K/W]	0.13	σ [W/m²K⁴]	5.67E-08

geometrical data

a [m]	3.0	A_g [m²]	2.43	A_{tot} [m²]	6
b [m]	2.0	A_f [m²]	3.57		
a' [m]	0.9	l_g [m]	10.8		
b' [m]	0.9	number of glasses	3		

frame and glass

Material [-]	metal	U_f [W/m²K]	2.80	U_g [W/m²K]	1.00
				ψ_g [W/mK]	0.05 *
				Rtot	1.00

*from sheet "Reference tables"

glazing properties

Glazing 1		Glazing 2		Glazing 3	
d_{g1} [m]	0.004	d_{g2} [m]	0.004	d_{g3} [m]	0.004
λ_{g1} [W/mK]	1	λ_{g2} [W/mK]	1	λ_{g3} [W/mK]	1

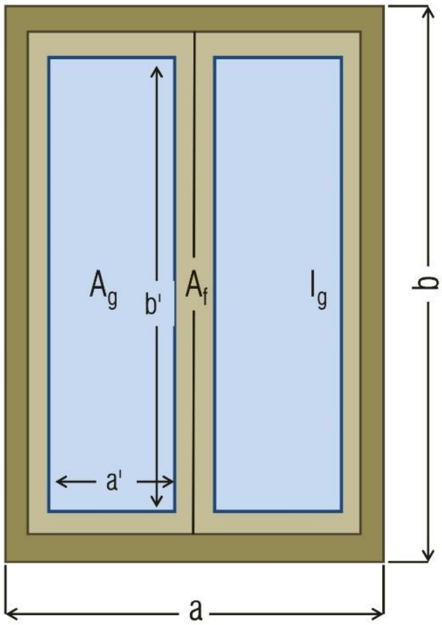
spaces (air or gas)

Space 1		Space 2	
d_{s1} [m]	0.016	d_{s2} [m]	0.012
λ_{s1} [W/mK]	0.01684	λ_{s2} [W/mK]	0.01684
ε_1 [-]	0.837	ε_1 [-]	0.837
ε_2 [-]	0.03	ε_2 [-]	0.03
h_r [W/m²K]	0.15	h_r [W/m²K]	0.15
h_g [W/m²K]	1.05	h_g [W/m²K]	1.40
Ug	1.00		

results

R_v [m²K/W]	0.004	U_w [W/m²K]	2.16
R_s [m²K/W]	0.829		

data to be input



$$U_g = \frac{1}{R_{se} + \sum_i R_{v,i} + \sum_j R_{s,j} + R_{si}}$$

$$U_w = \frac{A_g U_g + A_f U_f + l_g \Psi_g}{A_g + A_f}$$

Fig 3.24 U-value calculation of triple glasses windows

fixes values

R_{se} [m²K/W]	0.04	T_m [K]	283.15
R_{si} [m²K/W]	0.13	σ [W/m²K⁴]	5.67E-08

geometrical data

a [m]	31.0	A_g [m²]	12	A_{tot} [m²]	62
b [m]	2.0	A_f [m²]	50		
a' [m]	0.5	l_g [m]	72		
b' [m]	1.0	number of glasses	24		

frame and glass

Material [-]	metal	U_f [W/m²K]	2.80	U_g [W/m²K]	1.00
				ψ_g [W/mK]	0.05 *
				Rtot	1.00

*from sheet "Reference tables"

glazing properties

Glazing 1		Glazing 2		Glazing 3	
d_{g1} [m]	0.004	d_{g2} [m]	0.004	d_{g3} [m]	0.004
λ_{g1} [W/mK]	1	λ_{g2} [W/mK]	1	λ_{g3} [W/mK]	1

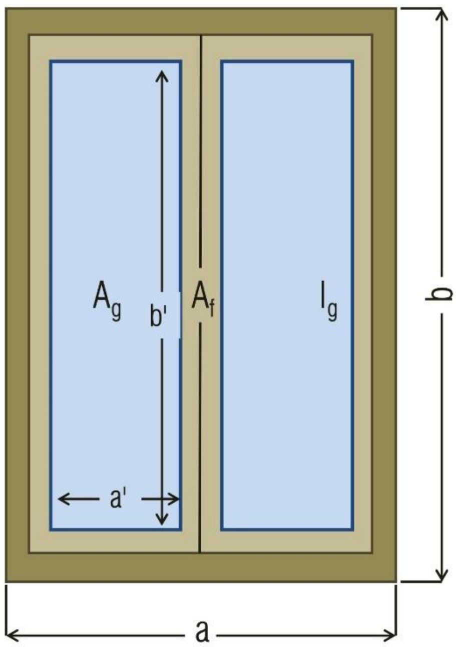
spaces (air or gas)

Space 1		Space 2	
d_{s1} [m]	0.016	d_{s2} [m]	0.012
λ_{s1} [W/mK]	0.01684	λ_{s2} [W/mK]	0.01684
ε_1 [-]	0.837	ε_1 [-]	0.837
ε_2 [-]	0.03	ε_2 [-]	0.03
h_r [W/m²K]	0.15	h_r [W/m²K]	0.15
h_g [W/m²K]	1.05	h_g [W/m²K]	1.40
Ug	1.00		

results

R_v [m²K/W]	0.004	U_w [W/m²K]	2.51
R_s [m²K/W]	0.829		

data to be input



$$U_g = \frac{1}{R_{se} + \sum_i R_{v,i} + \sum_j R_{s,j} + R_{si}}$$

$$U_w = \frac{A_g U_g + A_f U_f + l_g \Psi_g}{A_g + A_f}$$

Fig 3.25 U-value Calculation of Curtain wall

Climate data result:

Below you can see result of 1 year of Turin's climate data from March 1st 2022 until February 28th. In this table we need average temperature of the year during cold and hot time of the year.

name	datetime	tempmax	tempmin	temp
turin	01/03/2022	8.2	1.2	4.1
turin	02/03/2022	10.3	2.6	5.8
turin	03/03/2022	12.6	5.7	8
turin	04/03/2022	10.6	3.9	6.8
turin	05/03/2022	7.5	3.2	4.9
turin	06/03/2022	8	2.1	4.2
turin	07/03/2022	9.3	1.7	4.7
turin	08/03/2022	4.9	0.2	2.8
turin	09/03/2022	10.6	0.7	4.5
turin	10/03/2022	12	3.5	7
turin	11/03/2022	7.1	1.4	5.1
turin	12/03/2022	4.3	2.2	3.4
turin	13/03/2022	5.9	3	4.2
turin	14/03/2022	8	2.1	5.1
turin	15/03/2022	9.8	4.3	6.8
turin	16/03/2022	12.2	5.8	8.2
turin	17/03/2022	8.2	6.9	7.5
turin	18/03/2022	10.9	7.1	8.8
turin	19/03/2022	12.8	4.9	7.8
turin	20/03/2022	10.9	3.1	6.5
turin	21/03/2022	11.1	4.2	7
turin	22/03/2022	12.8	4.8	8.1
turin	23/03/2022	16.2	5.7	10.2
turin	24/03/2022	18.2	9.3	12.5
turin	25/03/2022	17.2	7.1	11.9
turin	26/03/2022	17.1	8.7	12.3
turin	27/03/2022	15.4	9.7	12.4
turin	28/03/2022	18.9	9.7	13.6
turin	29/03/2022	16.8	8	12.2
turin	30/03/2022	10.1	6.3	7.7
turin	31/03/2022	13.2	6.1	8.8
turin	01/04/2022	12.4	3.3	7
turin	02/04/2022	6.6	1.9	4.3
turin	03/04/2022	9.9	3.2	5.9
turin	04/04/2022	10.5	3.2	6.8
turin	05/04/2022	16.6	1.9	9.3
turin	06/04/2022	13.2	5.7	10
turin	07/04/2022	18.4	6.7	12.2
turin	08/04/2022	20.2	7	14.2
turin	09/04/2022	17.1	9.9	13.3
turin	10/04/2022	15.5	2.7	9.2
turin	11/04/2022	16.5	3.9	10.2
turin	12/04/2022	16.9	5.6	11.9
turin	13/04/2022	18.8	9.7	14
turin	14/04/2022	21.1	8.7	15.1
turin	15/04/2022	23	9.8	16.8
turin	16/04/2022	21.5	11.8	17.2
turin	17/04/2022	16.8	8.3	13.3
turin	18/04/2022	17.1	7.3	12.4
turin	19/04/2022	18.1	6.9	12.9
turin	20/04/2022	11.9	7.6	9.4
turin	21/04/2022	11.9	8.2	10
turin	22/04/2022	17.5	8.9	12.3
turin	23/04/2022	13.8	9.6	11.1
turin	24/04/2022	14.1	6.3	10.4
turin	25/04/2022	16.2	8.6	12.7
turin	26/04/2022	18.1	9.3	13.6
turin	27/04/2022	19	10.3	14.7
turin	28/04/2022	21.7	11.2	16
turin	29/04/2022	19.8	11.2	15.2
turin	30/04/2022	17.2	11.3	14.6
turin	01/05/2022	18.9	9.6	14.4
turin	02/05/2022	19.8	10.2	15.2
turin	03/05/2022	17.1	12.3	14.5
turin	04/05/2022	17.4	12.1	14.3
turin	05/05/2022	13	10.3	11.8
turin	06/05/2022	12.9	9.3	11.6
turin	07/05/2022	17.2	11.1	13.6
turin	08/05/2022	17.2	11.3	14.3
turin	09/05/2022	20.2	12.9	16.7
turin	10/05/2022	22.8	11.9	17.9
turin	11/05/2022	26.4	13.8	19.9
turin	12/05/2022	26.6	13.9	20.1
turin	13/05/2022	24.6	15.8	20.2
turin	14/05/2022	25.8	16.2	20.9
turin	15/05/2022	24.4	17.8	21.1
turin	16/05/2022	26.6	15.7	21
turin	17/05/2022	27.8	15.9	22
turin	18/05/2022	26.1	18.8	22.4
turin	19/05/2022	26.3	17.3	21.5
turin	20/05/2022	27.8	16.9	22.1
turin	21/05/2022	29.6	17.2	23.1
turin	22/05/2022	26.8	17.8	22.3
turin	23/05/2022	26.2	18.8	21.9
turin	24/05/2022	25.2	15.9	19.8
turin	25/05/2022	21.8	15.2	18
turin	26/05/2022	24.8	15.9	20.3
turin	27/05/2022	28.7	17.8	22.5
turin	28/05/2022	29.2	18.2	22.8
turin	29/05/2022	18	12.1	15
turin	30/05/2022	17.8	12.2	15.3
turin	31/05/2022	21.3	13.9	17.6
turin	01/06/2022	23.8	16.2	19.9
turin	02/06/2022	25.7	18.3	22.1
turin	03/06/2022	22.7	18.6	20.2
turin	04/06/2022	26.8	17.3	21.8
turin	05/06/2022	27.7	20.4	23.3
turin	06/06/2022	27.5	17.8	22.6

name	datetime	tempmax	tempmin	temp
turin	07/06/2022	26.2	17.9	21.9
turin	08/06/2022	24.5	17	20.8
turin	09/06/2022	25.8	14.9	20.9
turin	10/06/2022	28.5	13.7	21.3
turin	11/06/2022	29.8	15.7	22.7
turin	12/06/2022	30.8	16.8	24.2
turin	13/06/2022	30.5	19.8	25.3
turin	14/06/2022	27.9	19.4	24.2
turin	15/06/2022	28.6	21.2	24.4
turin	16/06/2022	32	20.9	26.4
turin	17/06/2022	31.8	21.5	26.7
turin	18/06/2022	29.9	20.5	25.4
turin	19/06/2022	29.8	21.9	25.6
turin	20/06/2022	31.8	21.3	26.2
turin	21/06/2022	29.1	21.2	24.8
turin	22/06/2022	24.1	19.2	21.9
turin	23/06/2022	25.3	19.1	22
turin	24/06/2022	25.4	18.3	21.7
turin	25/06/2022	28.2	16.8	22
turin	26/06/2022	26.6	19.3	22.6
turin	27/06/2022	28.9	19.9	24.5
turin	28/06/2022	24.9	16	21
turin	29/06/2022	30.2	17.9	23.2
turin	30/06/2022	28.1	19	23.8
turin	01/07/2022	28.8	17	22.9
turin	02/07/2022	30.2	20.8	25
turin	03/07/2022	32.8	21.7	26.7
turin	04/07/2022	28.8	21.9	25.2
turin	05/07/2022	32.2	19.8	25.7
turin	06/07/2022	29.8	20.5	25.3
turin	07/07/2022	30.7	21.1	25.6
turin	08/07/2022	31.4	19	24.9
turin	09/07/2022	29.1	17.8	23.8
turin	10/07/2022	30.4	18.1	24.7
turin	11/07/2022	29.8	19.4	24.5
turin	12/07/2022	29.2	19.3	24.7
turin	13/07/2022	29.9	20.3	25
turin	14/07/2022	32.4	20.9	26.5
turin	15/07/2022	35.1	20.6	27.5
turin	16/07/2022	32.8	21.9	27
turin	17/07/2022	31.3	22.5	26.6
turin	18/07/2022	32.3	22.4	27.2
turin	19/07/2022	31.2	23.4	27.5
turin	20/07/2022	32.4	24.2	28.2
turin	21/07/2022	33.3	21.9	27.8
turin	22/07/2022	33.4	23.8	28.3
turin	23/07/2022	31.3	23.4	27.3
turin	24/07/2022	31.7	22.9	27.6
turin	25/07/2022	33.8	22.9	28.6
turin	26/07/2022	31.9	19.9	26.3
turin	27/07/2022	28.2	20	24.1
turin	28/07/2022	27.7	21.3	24.8
turin	29/07/2022	24.7	20	22.2
turin	30/07/2022	28.8	17	23.3
turin	31/07/2022	30.7	19.8	26
turin	01/08/2022	32.8	20.7	27
turin	02/08/2022	29.3	22.7	25.9
turin	03/08/2022	30.9	21.9	26.9
turin	04/08/2022	32.6	22.8	27.8
turin	05/08/2022	33.3	24.3	28.1
turin	06/08/2022	33.4	22.6	28
turin	07/08/2022	28.2	20.1	23.6
turin	08/08/2022	29.9	17.8	24.2
turin	09/08/2022	29.1	16	24.5
turin	10/08/2022	28.7	21.9	25.6
turin	11/08/2022	28.7	19.9	24.7
turin	12/08/2022	28.2	19.8	24.2
turin	13/08/2022	27.3	18.3	23
turin	14/08/2022	25.2	16	21.8
turin	15/08/2022	27.9	16.7	22.8
turin	16/08/2022	28.3	17	23.1
turin	17/08/2022	23.7	19	21.2
turin	18/08/2022	21.3	17.1	19.4
turin	19/08/2022	26.1	16.8	21.4
turin	20/08/2022	29.1	18.7	23.8
turin	21/08/2022	29.7	19.7	24.6
turin	22/08/2022	30.4	18.9	24.2
turin	23/08/2022	30.8	21.5	25.5
turin	24/08/2022	29.2	18.7	23.9
turin	25/08/2022	30.2	19.8	25
turin	26/08/2022	27.2	20.9	23.6
turin	27/08/2022	28.6	17.8	23.2
turin	28/08/2022	29.2	18.9	23.5
turin	29/08/2022	28.8	20	24
turin	30/08/2022	25.3	20.2	22.2
turin	31/08/2022	26.4	17.7	21.9
turin	01/09/2022	26.5	19.1	22.3
turin	02/09/2022	22.3	17.2	20.2
turin	03/09/2022	22.3	17.9	19.9
turin	04/09/2022	26.2	16.9	21.2
turin	05/09/2022	27.4	19	22.8
turin	06/09/2022	27.9	18.8	23.5
turin	07/09/2022	26.4	19.9	22.3
turin	08/09/2022	24.7	17.8	21.2
turin	09/09/2022	26.8	16.8	21.3
turin	10/09/2022	25.8	15.5	20.2
turin	11/09/2022	26.2	12.9	20.5
turin	12/09/2022	27.4	14.9	20.8

name	datetime	tempmax	tempmin	temp
turin	13/09/2022	25.9	15.8	21.3
turin	14/09/2022	24.4	17.9	21.1
turin	15/09/2022	28.7	15.9	22.2
turin	16/09/2022	28	16.7	22.5
turin	17/09/2022	23.4	14	19.7
turin	18/09/2022	23.4	8.7	16.3
turin	19/09/2022	24	9.9	16.9
turin	20/09/2022	23.4	11	17.2
turin	21/09/2022	15.9	11.8	14.6
turin	22/09/2022	21.4	13	16.3
turin	23/09/2022	21.4	14.9	17
turin	24/09/2022	16.9	12.1	13.8
turin	25/09/2022	16.8	11.4	14.1
turin	26/09/2022	19.9	9.9	14.9
turin	27/09/2022	21.3	10.8	15.8
turin	28/09/2022	20.4	10.7	14.7
turin	29/09/2022	19.8	10.9	14.7
turin	30/09/2022	14.9	10.9	12.7
turin	01/10/2022	18.9	10.6	14.2
turin	02/10/2022	21.7	10.8	15.9
turin	03/10/2022	24.3	11.7	18
turin	04/10/2022	20.3	13.6	16.9
turin	05/10/2022	19.3	15.7	17.9
turin	06/10/2022	21.1	13.9	17.7
turin	07/10/2022	21.2	15	18.1
turin	08/10/2022	20.4	12.9	16.5
turin	09/10/2022	16	13.2	14.6
turin	10/10/2022	15.7	12.2	14.2
turin	11/10/2022	19.7	9.9	14.8
turin	12/10/2022	19.1	12.8	15.7
turin	13/10/2022	18.7	12.7	15.5
turin	14/10/2022	19.2	11	15.1
turin	15/10/2022	18.9	12.2	15.9
turin	16/10/2022	18.9	14.1	17.3
turin	17/10/2022	20.3	15.2	17.5
turin	18/10/2022	21.9	12.9	16.8
turin	19/10/2022	22.3	12.8	17.4
turin	20/10/2022	18.9	13.8	16.7
turin	21/10/2022	16.8	14.9	15.6
turin	22/10/2022	18.7	14.2	16.4
turin	23/10/2022	17.9	14.3	16
turin	24/10/2022	17.9	14.2	16.3
turin	25/10/2022	18.8	12.9	16
turin	26/10/2022	19.7	14.8	16.8
turin	27/10/2022	20.1	12.9	16.3
turin	28/10/2022	21.1	12.8	16.4
turin	29/10/2022	22.1	11.8	16.2
turin	30/10/2022	20.9	10.9	16
turin	31/10/2022	21.4	11	16
turin	01/11/2022	16.2	11	13.4
turin	02/11/2022	15.5	8.8	11.9
turin	03/11/2022	15.3	10.9	12.8
turin	04/11/2022	13.7	9.2	11.6
turin	05/11/2022	16.8	6	11.5
turin	06/11/2022	15.2	4.8	10.2
turin	07/11/2022	15.1	3.8	10
turin	08/11/2022	14.9	6.9	10.9
turin	09/11/2022	13.9	5.9	10.2
turin	10/11/2022	15.1	8	11.2
turin	11/11/2022	13.7	6.2	10.2
turin	12/11/2022	14.6	5.9	10.8
turin	13/11/2022	12.8	7.1	10.2
turin	14/11/2022	9.9	7	8.7
turin	15/11/2022	9.3	6.2	8.1
turin	16/11/2022	11.4	5.8	8.6
turin	17/11/2022	10.8	4.9	8.4
turin	18/11/2022	15.2	6.1	10
turin	19/11/2022	11.4	3.8	7.5
turin	20/11/2022	11.4	1.7	6.4
turin	21/11/2022	9.1	0.8	5.6
turin	22/11/2022	10.7	2.8	6.6
turin	23/11/2022	12	1	6.4
turin	24/11/2022	13.4	-1	7.4
turin	25/11/2022	10.7	4.7	7.4
turin	26/11/2022	13.2	1.8	7.4
turin	27/11/2022	9.7	2.7	6
turin	28/11/2022	6.9	1	4.6
turin	29/11/2022	5	1.9	4.1
turin	30/11/2022	5.5	-0.2	3.4
turin	01/12/2022	8.9	-0.1	4.3
turin	02/12/2022	5.9	2.1	4.3
turin	03/12/2022	5.9	2.4	4.3
turin	04/12/2022	6.9	3.2	5.5
turin	05/12/2022	8.2	4.2	6.3
turin	06/12/2022	7.7	1	4.3
turin	07/12/2022	5.9	-0.2	2.7
turin	08/12/2022	5.9	-1	2.1
turin	09/12/2022	3.9	1.2	2.4
turin	10/12/2022	6.3	-0.9	2.6
turin	11/12/2022	6.3	-2.9	1.5
turin	12/12/2022	0.7	-3	-1.2
turin	13/12/2022	2.4	-2.7	0
turin	14/12/2022	3.3	-1.2	0.8
turin	15/12/2022	1.7	-3.1	-0.5
turin	16/12/2022	3.2	-0.4	1
turin	17/12/2022	5.7	-3.1	1.7
turin	18/12/2022	4.7	0.6	2.1
turin	19/12/2022	2.9	-1.4	0.9

name	datetime	tempmax	tempmin	temp
turin	20/12/2022	4.9	-2.3	1.7
turin	21/12/2022	5.7	0.8	3.4
turin	22/12/2022	7.1	-1.2	3.3
turin	23/12/2022	7.1	-0.2	4
turin	24/12/2022	7.7	5.3	6.3
turin	25/12/2022	7.8	5.3	7.1
turin	26/12/2022	10.7	4.7	7.5
turin	27/12/2022	10	2.8	6.1
turin	28/12/2022	7.4	2.8	5.4
turin	29/12/2022	7.9	1.2	4.4
turin	30/12/2022	7.3	0.9	4.2
turin	31/12/2022	8.2	1	4.7
turin	01/01/2023	7.9	5.4	6.5
turin	02/01/2023	8.9	6.2	7.8
turin	03/01/2023	9.9	7.1	8.5
turin	04/01/2023	10	4.7	7.8
turin	05/01/2023	11.2	2.9	6.9
turin	06/01/2023	6.8	2.9	5.1
turin	07/01/2023	6.9	4.1	5.3
turin	08/01/2023	6.9	4.2	5.2
turin	09/01/2023	10.4	1.9	5.9
turin	10/01/2023	11.4	2.8	8.1
turin	11/01/2023	8.8	0.9	5.2
turin	12/01/2023	9.3	0.5	5
turin	13/01/2023	8.4	0.7	4.3
turin	14/01/2023	8.1	0	4.5
turin	15/01/2023	6.1	1.2	3.6
turin	16/01/2023	2.8	-1.8	1.1
turin	17/01/2023	2.9	-1.9	1.1
turin	18/01/2023	2.7	-0.8	0.5
turin	19/01/2023	4.3	-1.1	0.8
turin	20/01/2023	3.5	-4.1	-0.5
turin	21/01/2023	4.5	-4	0.1
turin	22/01/2023	3.3	-1.9	0.7
turin	23/01/2023	4.9	-2.8	1.5
turin	24/01/2023	5.5	1.5	3.9
turin	25/01/2023	6.1	0.9	3.3
turin	26/01/2023	5.3	-0.2	2.2
turin	27/01/2023	2.7	-0.8	1.1
turin	28/01/2023	4.3	0	2
turin	29/01/2023	4.3	-3.1	0.9
turin	30/01/2023	7.1	-1.3	2
turin	31/01/2023	9.2	-1.1	4.3
turin	01/02/2023	10.3	-0.8	5
turin	02/02/2023	11.3	-0.2	6.3
turin	03/02/2023	12.5	2.6	7.3
turin	04/02/2023	16.6	3.7	10.6
turin	05/02/2023	7.9	1.2	4.3
turin	06/02/2023	4.9	1.2	3.1
turin	07/02/2023	4.2	-2.7	1
turin	08/02/2023	3.2	-2.2	0.4
turin	09/02/2023	2.1	-3.6	-0.6
turin	10/02/2023	5.1	-4.2	0
turin	11/02/2023	8	-4.1	2.4
turin	12/02/2023	12.9	-1.1	6.8
turin	13/02/2023	12.3	0.9	6.6
turin	14/02/2023	14	-0.1	7.5
turin	15/02/2023	15.6	1.7	8.9
turin	16/02/2023	13.6	3.6	8.7
turin	17/02/2023	12.9	2.7	7.6
turin	18/02/2023	13.8	3.4	8.2
turin	19/02/2023	14	1.9	8
turin	20/02/2023	10.7	2.9	7.2
turin	21/02/2023	11.3	6.1	9
turin	22/02/2023	10	8.1	9.1
turin	23/02/2023	11.9	7.1	9.4
turin	24/02/2023	10.7	7.1	9
turin	25/02/2023	11	3.9	7.6
turin	26/02/2023	6.7	0.2	2.7
turin	27/02/2023	3.8	0.1	1.9
turin	28/02/2023	4.1	1.2	2.9
turin	01/03/2023	5.9	2	4

Table 3.6 Turin's temperature data during 1 year (From 01/03/2022 to 28/02/2023)

Average Outside Temperature (T1)	*Desired Temperature(T2) Winter*	*Difference Temperature*
14.4847541	*24*	*9.515245902*
16.30921053	*24*	*7.690789474*
15.39698231	*24*	*8.603017688*

To calculate heating and cooling load of the building we have to consider average temperature of the outside in the calculations. Desired temperature would be the best temperature for the people who are working in the office.

Infiltration load:

In the heating load assessment, calculating the infiltration load entails measuring the heat loss owing to air leakage or infiltration through cracks, gaps, and holes in the building envelope. While more thorough techniques for calculating infiltration load exist, here is a basic way based on the air change rate:

Infiltration Load = (Building Volume × Air Change Rate) × Specific Heat Capacity × Temperature Difference

About the specific heat capacity is a property of air that quantifies the amount of heat energy required to change its temperature. The specific heat capacity of air is typically around 1.006 kJ/kg·K or 0.24 Btu/lb·°F.

In a well-sealed and modern commercial office building, the average **air change rate** is commonly estimated to be around 0.5 to 1 air changes per hour (ACH). This means that the volume of air inside the building is completely replaced with outdoor air every 0.5 to 1 hour. In this case we assume the air change rate would be near **1.5 ACH** because of old design of air ventilation in that building.

Building volume : Length × Width × Height ⟶ Building Volume : 34.57 × 12.76 × 7.70 = 3396 m^3

Infiltration load = (3396 × 1.5) × 1.006 × 8.60 = 44071 KWh

Ventilation Load:

Ventilation rate: The ventilation rate represents the amount of fresh air required to maintain indoor air quality. It is typically expressed in terms of air changes per hour (ACH) or volume flow rate (cubic meters per hour or cubic feet per minute). The ventilation rate depends on factors such as the building occupancy, type of space, and local ventilation standards or guidelines.

Ventilation Load = Ventilation Rate × Specific Heat Capacity × Temperature Difference

Ventilation rate based on standards for offices in Italy would be 4 l/s which can be recalculate to Cubic meter per minutes.

To convert liters per second (l/s) to cubic meters per minute (m^3/min), you can use the following conversion factor:

1 cubic meter per minute = 16.6667 liters per second

To convert 4 l/s to m^3/min, you can multiply the flow rate in liters per second by the conversion factor:

4 l/s * (1 m^3/min / 16.6667 l/s) = **0.24 m^3/min**

Therefore, 4 liters per second is equivalent to 0.24 cubic meters per minute.

Average Ventilation Rate = Ventilation Rate per Occupant × Number of Occupants

Average Ventilation Rate = 0.24 cmm/occupant × 52 occupants

Average Ventilation Rate = 12.48 cubic meter per minute

Ventilation Load = 12.78 × 1.006 × 8.60 = 110.56 KWh

3.2.2 Energy Model

Energy modeling plays a crucial role in the design and evaluation of buildings by providing valuable insights into their energy consumption, efficiency, and sustainability. Through the use of advanced software tools and simulation techniques, energy models simulate the energy performance of a building, taking into account factors such as climate, building envelope, HVAC systems, lighting, and occupant behavior.

One of the key benefits of energy modeling is its ability to inform design decisions and optimize energy efficiency. By analyzing different design options and their corresponding energy impacts, architects and engineers can identify opportunities for improvement and implement energy-saving strategies early in the design process. This includes evaluating the performance of different building components, such as insulation, windows, and lighting systems, and selecting the most energy-efficient options. Energy modeling also allows for the assessment of renewable energy systems, such as solar panels or wind turbines, and their integration into the building design, further reducing reliance on traditional energy sources.

Another advantage of energy modeling is its ability to support sustainable building certifications and compliance with energy codes and standards. Energy models provide a quantitative assessment of a building's energy performance, allowing designers to demonstrate compliance with specific energy efficiency requirements. This is particularly important in achieving certifications such as LEED (Leadership in Energy and Environmental Design) or ENERGY STAR ratings, which highlight a building's environmental performance. By accurately predicting energy consumption, energy models enable design teams to make data-driven decisions, optimize energy efficiency, and ensure buildings meet or exceed regulatory and sustainability goals.

Fig 3.26 Zone of the offices - Current plan

To determine the energy model of a building, it is necessary to first identify the spaces that are involved in this analysis as energy analysis spaces and determine the components of each of these spaces. These spatial divisions are of great importance, as they allow for the precise identification of energy analysis factors such as the type of usage, HVAC system (heating and cooling), lighting and electricity, usable hours (as shown in the table below), and the number of occupants present in the room for using that space. It is obvious that these points are essential for determining the energy consumption in this facility.

As seen in the previous floor plan and this page, in this project, we have three main categories of spaces before interior design:

1- Enclosed office spaces
2- Corridors
3- Restrooms

Most of these spaces constitute enclosed office rooms, and the settings should be considered for these areas.

Fig 3.27 Zone of the offices - Project plans

However, after the redesign of the interior space of this office, we realize that there are no longer any enclosed office spaces, and the office has transitioned to open workspaces. Additionally, new functional spaces such as a conference room and meeting room have been added. The important point here is the transformation of the office spaces from enclosed rooms to open workspaces.

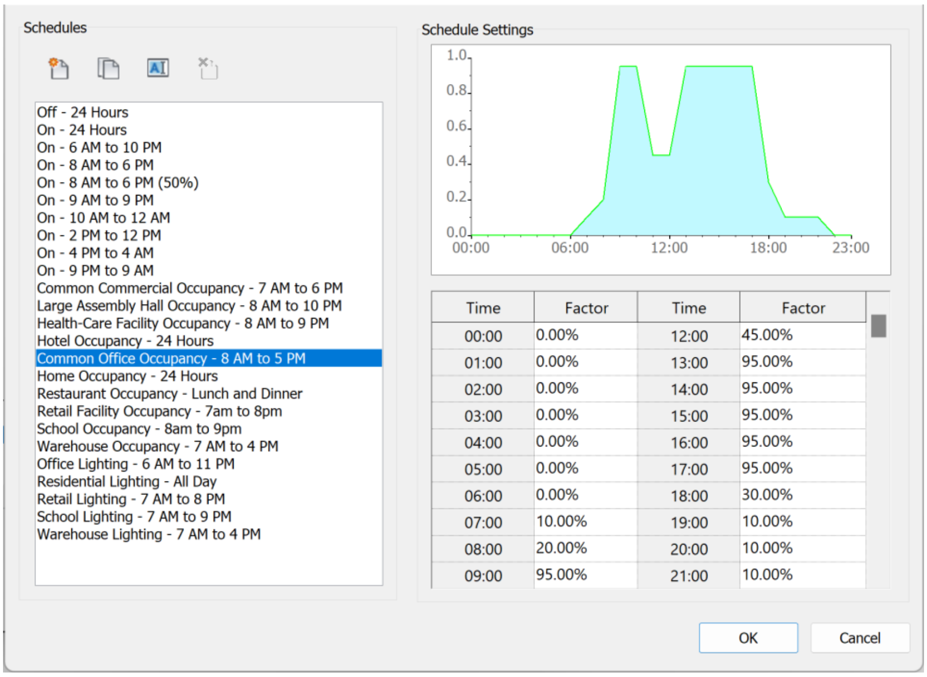


Fig 3.28 Time schedule of the offices for analysis

After identifying the energy spaces and room settings, the next step is to create an energy model for data analysis. These energy models specifically examine the thermal envelope and its impact on heat transfer (a crucial aspect of our discussion), as well as internal factors influencing HVAC calculations and electricity consumption.

Below, you can see three visual models of these energy models, categorized into three types:

1- Interior energy model 2- Exterior envelope energy model 3- Combination of the two aforementioned models

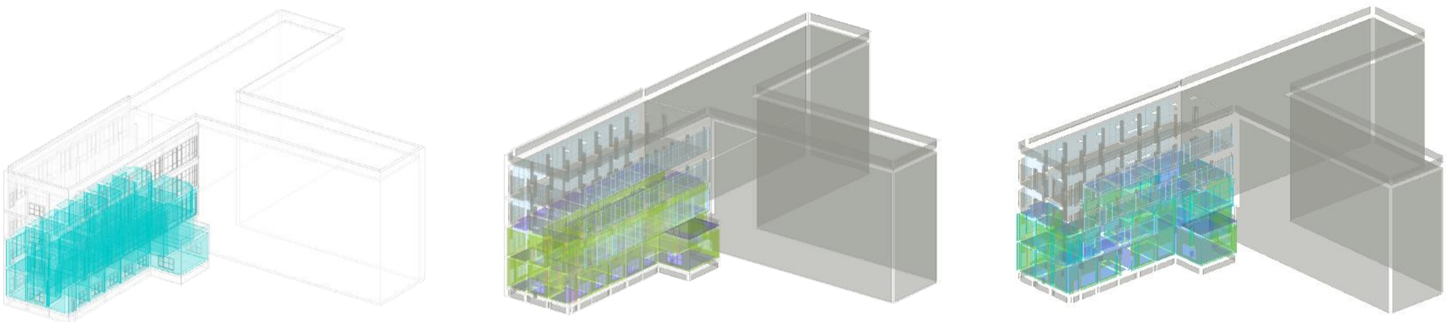


Fig 3.29 Energy Model sectors

4. Result and Discission

4.1 Analysis of the result in energy and design phase

After all these steps, we finally arrived at the result of the project to check and compare to find out how close we are to the goal of this thesis. In the first place, designing and its result would be more important for this project. Additionally, until now, the stated problem about the interior design and renovation part has been solved, and here we only want to observe quickly the process of the renovation and changes.

COMPARE SPACES(BEFORE-AFTER NEW DESIGN):

SPACE CATEGORY	CURRENT STATE	PROJECT	CURRENT CAPACITY	PROJECT CAPACITY
WORKING AREAS	334 m^2	340.5 m^2	31	53(71%)
BUILDING SERVICES	74 m^2	29 m^2	-	-
SUPPORTING AREAS	30 m^2	68.5 m^2	14	22(57.2%)

COMPARE SPACES(BEFORE-AFTER NEW DESIGN):

SPACE CATEGORY	CURRENT STATE	PROJECT	CURRENT CAPACITY	PROJECT CAPACITY
WORKING AREAS	312 m^2	331 m^2	33	52(62.4%)
BUILDING SERVICES	105 m^2	39 m^2	-	-
SUPPORTING AREAS	-	43 m^2	-	18

Fig 4.1 Comparing before and after of re-designing the offices

On the contrary, the critical problem of energy, which is critical in today's world, has been investigated in this project, and its stages have been mentioned above, incorporating mathematical formulae and analysis through the use of energy analysis software such as BIM. Now, let us look at the findings of this energy analysis in different section of the energy analysis:

1- Input verification and Result summary

General

	Value
Program Version and Build	EnergyPlus, Version 9.1.0-fafb9d5652, YMD=2023.07.03 10:46
RunPeriod	RUN PERIOD 1
Weather File	Torino Bric della Croce PM ITA ISD-TMYx WMO#=160610
Latitude [deg]	45.03
Longitude [deg]	7.73
Elevation [m]	710.00
Time Zone	1.00
North Axis Angle [deg]	0.00
Rotation for Appendix G [deg]	0.00
Hours Simulated [hrs]	8760.00

Window-Wall Ratio

	Total	North (315 to 45 deg)	East (45 to 135 deg)	South (135 to 225 deg)	West (225 to 315 deg)
Gross Wall Area [m2]	769.05	131.94	268.93	122.41	245.76
Above Ground Wall Area [m2]	769.05	131.94	268.93	122.41	245.76
Window Opening Area [m2]	284.04	5.88	126.38	17.64	134.14
Gross Window-Wall Ratio [%]	36.93	4.46	46.99	14.41	54.58
Above Ground Window-Wall Ratio [%]	36.93	4.46	46.99	14.41	54.58

Table 4.1 Input Verification data (General and Envelope)

2- Annual utility performance summary

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	956.56	1492.83	1492.83
Net Site Energy	956.56	1492.83	1492.83
Total Source Energy	2426.57	3786.96	3786.96
Net Source Energy	2426.57	3786.96	3786.96

Current Situation

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	722.97	1026.80	1026.80
Net Site Energy	722.97	1026.80	1026.80
Total Source Energy	1632.94	2319.20	2319.20
Net Source Energy	1632.94	2319.20	2319.20

Project Analysis

Table 4.2 Annual utility performance

3- Performance - Zone summary

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Above Ground Gross Wall Area [m2]	Underground Gross Wall Area [m2]	Window Glass Area [m2]	Opening Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
CORRIDOR 20	51.77	Yes	Yes	218.64	1.00	8.12	0.00	0.00	0.00	5.3820	8.63	3.2292
WC 37	19.97	Yes	Yes	97.60	1.00	58.29	0.00	13.94	13.94	9.6875	6.66	3.2292
WC 9	24.10	Yes	Yes	84.84	1.00	17.36	0.00	5.88	5.88	9.6875	8.03	3.2292
ZONE 1	306.13	Yes	Yes	1237.81	1.00	426.55	0.00	94.03	94.03	11.8403	9.57	16.1459
ZONE 2	238.80	Yes	Yes	1247.56	1.00	724.12	0.00	286.53	286.53	11.8403	7.96	16.1459
Total	640.77			2886.45		1234.44	0.00	400.38	400.38	11.1705	8.66	14.2139
Conditioned Total	640.77			2886.45		1234.44	0.00	400.38	400.38	11.1705	8.66	14.2139
Unconditioned Total	0.00			0.00		0.00	0.00	0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00	0.00	0.00			

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Above Ground Gross Wall Area [m2]	Underground Gross Wall Area [m2]	Window Glass Area [m2]	Opening Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
ANALYTICAL SPACE 1	12.61	Yes	Yes	61.37	1.00	12.91	0.00	12.08	12.08	10.7639	12.61	13.9931
ANALYTICAL SPACE 2	4.53	Yes	Yes	30.99	1.00	9.75	0.00	9.00	9.00	10.7639	4.53	13.9931
CONFERENCE ROOM 11	18.50	Yes	Yes	70.72	1.00	38.87	0.00	5.88	5.88	13.9931	1.85	10.7639
CORRIDOR 16	111.73	Yes	Yes	491.44	1.00	125.26	0.00	62.90	62.90	5.3820	9.31	3.2292
CORRIDOR 7	130.21	Yes	Yes	533.51	1.00	117.21	0.00	30.31	30.31	5.3820	9.30	3.2292
OFFICE 10	16.05	Yes	Yes	74.63	1.00	29.84	0.00	11.03	11.03	11.8403	2.68	16.1459
OFFICE 14	5.39	Yes	Yes	14.47	1.00	0.00	0.00	0.00	0.00	11.8403	0.90	16.1459
OFFICE 15	13.25	Yes	Yes	52.76	1.00	12.69	0.00	12.20	12.20	13.9931	4.42	10.7639
OFFICE 19	110.05	Yes	Yes	500.53	1.00	85.01	0.00	76.36	76.36	11.8403	5.50	16.1459
PHONE BOOTH 1 21	3.54	Yes	Yes	11.03	1.00	0.00	0.00	0.00	0.00	10.7639	3.54	13.9931
PHONE BOOTH 2 11	5.14	Yes	Yes	18.61	1.00	0.00	0.00	0.00	0.00	10.7639	5.14	13.9931
PHONE BOOTH 2 20	4.35	Yes	Yes	16.54	1.00	0.00	0.00	0.00	0.00	10.7639	4.35	13.9931
WC 17	19.14	Yes	Yes	73.39	1.00	20.67	0.00	0.00	0.00	9.6875	6.38	3.2292
WC 8	23.06	Yes	Yes	79.54	1.00	17.36	0.00	5.88	5.88	9.6875	5.76	3.2292
ZONE 1	226.55	Yes	Yes	884.46	1.00	299.48	0.00	58.39	58.39	12.2614	4.27	15.0932
Total	704.10			2914.00		769.05	0.00	284.04	284.04	9.6784	5.18	10.2596
Conditioned Total	704.10			2914.00		769.05	0.00	284.04	284.04	9.6784	5.18	10.2596
Unconditioned Total	0.00			0.00		0.00	0.00	0.00	0.00			
Not Part of Total	0.00			0.00		0.00	0.00	0.00	0.00			

Table 4.3 Zone summary of the current and project

4- Annual Heat Emission summary

By Components

	Envelope Convection	Zone Exfiltration	Zone Exhaust Air	HVAC Relief Air	HVAC Reject Heat	Total
Heat Emissions [GJ]	-7158.1	143.24	0.00	0.00	0.00	-7014.9

	Envelope Convection	Zone Exfiltration	Zone Exhaust Air	HVAC Relief Air	HVAC Reject Heat	Total
Heat Emissions [GJ]	-5543.9	151.77	0.00	0.00	0.00	-5392.1

Table 4.4 Heat emission from the component

End Use Percentage

5- End Use Percentage

	Percent [%]
Interior Lighting (All)	7.14
Space Heating	44.51
Space Cooling	39.26
Fans (All)	0.00
Service Water Heating	0.00
Receptacle Equipment	9.09
Miscellaneous	-0.00

Current Situation

	Percent [%]
Interior Lighting (All)	9.00
Space Heating	31.73
Space Cooling	49.73
Fans (All)	0.00
Service Water Heating	0.00
Receptacle Equipment	9.54
Miscellaneous	0.00

Project Analysis

Table 4.5 Percent of energy consumed by the elemnts

Cost estimation:

One of the main important aspect of the analysis of the project, attention to the cost of renovation and components of the new building. As you can see below the cost of the wall materials of the building related to the new interior material would be around 24515 Euro. Based on the average cost of electricity in Italy, the save money for the electricity would be around 21000 Euro per year.

Acoustic Mineral Wool: 46	1256.99 m²	2514	2513.98€
Gypsum Wall Board-project:	1256.87 m²	12569	12568.74€
Wood - Stud Layer: 46	628.85 m²	9433	9432.74€
Grand total: 249	28828.69 m²	24515	24515.47€

Table 4.6 Cost estimation 72

4.2 Comparison of the pre-renovation and post-renovation energy performance

Report: **BUILDING ENERGY PERFORMANCE - ELECTRICITY**

For: **Meter**

Timestamp: **2023-07-03 10:54:04**

Custom Monthly Report

	INTERIORLIGHTS:ELECTRICITY [J]	EXTERIORLIGHTS:ELECTRICITY []	INTERIOREQUIPMENT:ELECTRICITY [J]	EXTERIOREQUIPMENT:ELECTRICITY []
January	0.600132E+10	0.00	0.763642E+10	0.00
February	0.523601E+10	0.00	0.666260E+10	0.00
March	0.552461E+10	0.00	0.702983E+10	0.00
April	0.574621E+10	0.00	0.731181E+10	0.00
May	0.577971E+10	0.00	0.735444E+10	0.00
June	0.549111E+10	0.00	0.698721E+10	0.00
July	0.600132E+10	0.00	0.763642E+10	0.00
August	0.552461E+10	0.00	0.702983E+10	0.00
September	0.574621E+10	0.00	0.731181E+10	0.00
October	0.600132E+10	0.00	0.763642E+10	0.00
November	0.526951E+10	0.00	0.670523E+10	0.00
December	0.600132E+10	0.00	0.763642E+10	0.00
Annual Sum or Average	0.683233E+11		0.869384E+11	
Minimum of Months	0.523601E+10	0.00	0.666260E+10	0.00
Maximum of Months	0.600132E+10	0.00	0.763642E+10	0.00

Current Situation

	INTERIORLIGHTS:ELECTRICITY [J]	EXTERIORLIGHTS:ELECTRICITY []	INTERIOREQUIPMENT:ELECTRICITY [J]	EXTERIOREQUIPMENT:ELECTRICITY []
January	0.571361E+10	0.00	0.605667E+10	0.00
February	0.498500E+10	0.00	0.528431E+10	0.00
March	0.525976E+10	0.00	0.557557E+10	0.00
April	0.547074E+10	0.00	0.579922E+10	0.00
May	0.550263E+10	0.00	0.583303E+10	0.00
June	0.522787E+10	0.00	0.554176E+10	0.00
July	0.571361E+10	0.00	0.605667E+10	0.00
August	0.525976E+10	0.00	0.557557E+10	0.00
September	0.547074E+10	0.00	0.579922E+10	0.00
October	0.571361E+10	0.00	0.605667E+10	0.00
November	0.501689E+10	0.00	0.531812E+10	0.00
December	0.571361E+10	0.00	0.605667E+10	0.00
Annual Sum or Average	0.650479E+11		0.689535E+11	
Minimum of Months	0.498500E+10	0.00	0.528431E+10	0.00
Maximum of Months	0.571361E+10	0.00	0.605667E+10	0.00

Project Analysis

Table 4.7 Building energy performance (before and after renovation)

4.3 Evaluation of the energy performance of the renovated office

To assess the final outcome of the refurbishment project for the office space in the L Building at Polytechnic University of Turin, it is necessary to obtain the required information and perform software calculations, including energy load calculations for the building. By doing so, we can obtain the following results:

In the annual utility performance summary, total building energy (the "gross" energy consumed by the building) decreased from 956.56 [GJ] to 722.97 [GJ] and Total source energy (the total amount of raw fuel that is required to operate the building). It incorporates all transmission, delivery, and production losses. From 2426.57 [GJ], it decreased to 1632.94 [GJ].
About energy per total building area, the numbers also have a great discount rate. In Total building energy, from 1492.83 [MJ/m2] reduced to 1026.80 [MJ/m2], and in total source energy, from 3786.96 [MJ/m2] to 2319.20 [MJ/m2] decreased.

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	956.56	1492.83	1492.83
Total Source Energy	2426.57	3786.96	3786.96

Current Situation

	Total Energy [GJ]	Energy Per Total Building Area [MJ/m2]	Energy Per Conditioned Building Area [MJ/m2]
Total Site Energy	722.97	1026.80	1026.80
Total Source Energy	1632.94	2319.20	2319.20

Project Analysis

Table 4.8 Comparing Annual utility

One of the most exciting and fascinating results of the project was reducing energy use for lighting the interior spaces and offices. Of course, all the offices have windows and natural light, but open spaces are planned for working areas. For a sustainable building, we have to consider all the possible options to recover energy from the building. As the software analysis shows, from 11.1705 [W/m2] to 9.6784 [W/m2], which has a significant effect on the hole scale of the building.

	Area [m2]	Conditioned (Y/N)	Part of Total Floor Area (Y/N)	Volume [m3]	Multipliers	Above Ground Gross Wall Area [m2]	Underground Gross Wall Area [m2]	Window Glass Area [m2]	Opening Area [m2]	Lighting [W/m2]	People [m2 per person]	Plug and Process [W/m2]
Total	640.77			2886.45		1234.44	0.00	400.38	400.38	11.1705	8.66	14.2139

Current Situation

Total	704.10			2914.00		769.05	0.00	284.04	284.04	9.6784	5.18	10.2596

Project Analysis

Table 4.9 Comparing interior energy use for lighting

The point of our job in this project was to change the layer of the building to recover and stop using much energy. As we had an enormous problem and limitation to reduce energy consumption of the building (We couldn't destroy the walls or change the rotation of the building, and we could only renovate interior space), focusing on the walls would be the best choice to reduce energy consumption, and also changing the old insulation of the building has a great impact on envelop construction in the area of heat emissions, decreasing from 7158.1 [GJ] to 5543.9 [GJ] energy.

5. Conclusions

5.1 Summary of the study's findings for future

The purpose of this thesis was to research and apply sustainable ways to building restoration, workplace design, and energy efficiency, with the goals of increasing employee productivity, environmental well-being, and energy conservation. The study's findings shed light on the efficacy of various tactics in reaching these objectives.

To begin with, remodeling based on sustainable methods has proven its potential for improving building performance and lowering environmental impact. Significant reductions in energy consumption and greenhouse gas emissions were accomplished by combining energy-saving systems and materials, such as efficient HVAC systems, smart lighting controls, and renewable energy integration. The use of eco-friendly materials and the implementation of sustainable construction procedures contributed even more to resource conservation and environmental sustainability

The second step is the use of smart office technology, which has been shown to improve workplace productivity and employee enjoyment. The workplace environment becomes more responsive and flexible by combining automation technologies, intelligent sensors, and data analytics. This allows for more energy-efficient operations, better space usage, and customized comfort settings for personnel. The smart office idea encourages a productive and long-term work environment by allowing people to work smarter and more effectively. Moreover, the office's open-space design has effectively handled a 20% increase in the number of employees. The use of open floor plans, collaborative workspaces, and flexible layouts promotes employee communication, cooperation, and creativity. This method not only increases space usage, but it also fosters a sense of community and well-being, which leads to higher job satisfaction and productivity.

Furthermore, the use of acoustic phone booths and glass has effectively addressed the issue of noise pollution in the workplace. Acoustic phone booths offer secluded locations for phone conversations and concentrated work, decreasing distractions and improving concentration. The adoption of soundproofing glazing systems has reduced noise transmission from outside sources, resulting in a calmer and more comfortable work environment. These measures have dramatically enhanced employee well-being, productivity, and general satisfaction.

Finally, the research looked at the effect of different insulation materials on lowering the energy load of the workplace. It was discovered after extensive testing and research that the choice of insulation materials for walls and floors had a substantial impact on energy usage. Materials with higher thermal resistance and lower thermal conductivity performed better in terms of heat transfer and energy losses. The findings emphasize the necessity of careful material selection for increasing energy efficiency and lowering the office's overall energy burden.

In conclusion, the findings of this thesis highlight the significance and efficacy of sustainable renovation approaches, smart office technologies, open space design, noise reduction measures, and insulation material selection in achieving energy efficiency and creating a conducive work environment. Implementing these measures not only helps the environment, but it also improves employee well-being, productivity, and satisfaction.

More research into additional sustainable methods, such as indoor air quality management, green landscaping, and waste management measures, is needed. Long-term monitoring and post-occupancy assessments should also be carried out to assess the ongoing efficacy of existing measures and identify areas for improvement. Overall, this thesis adds to our understanding of sustainable construction practices, smart office technology, and energy efficiency measures. The findings are useful for architects, designers, and building owners who want to construct sustainable, intelligent, and productive workplaces. We can develop workplaces that promote environmental stewardship, employee well-being, and energy conservation by adopting sustainable principles, using smart technology, and employing evidence-based design techniques, paving the way for a more sustainable future.

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