ENERGY MANAGEMENT IN A MEDIUM-SIZED OFFICE BUILDING: NUDGING TOWARDS ZERO CARBON FOOTPRINT

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Declaration

No portion of the work referred to in the dissertation has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Signature of Student

Name of Student

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Abstract

Energy audits have become one of the primary approaches for determining energy saving opportunities in buildings, as they provide key information on deficiencies and potential improvements to reduce energy consumption and maximise energy efficiency.

This dissertation aims to analyse the energy performance of a medium-sized office building in the centre of Valletta, Malta. Three approaches have been implemented which included a walk-through survey for determining building and energy services characteristics, as well as measuring indoor air quality, analysis of one year energy consumption and modelling of the whole building in a specialised energy modelling software, DesignBuilder powered by EnergyPlus engine.

A number of energy efficiency measures were identified and analysed. A hierarchy of potential energy efficiency measures tailor-made for the different zones of the building have been identified together with their resulting energy saving potential.

Five possible measures are proposed in total, three regarding modifications on the building envelope of the building, installing shading devices, insulation and enhancing the double glazed windows with low emissivity (LoE) film and two measures regarding alterations to the energy systems, being the installation of desk lamps in the offices and lighting control.

The results obtained from the simulation show that measures like insulation, shading and lighting control provide substantial improvements for reducing energy consumption in the building. On the other hand, LoE windows and desk lamps do not perform sufficiently well to be implemented, although some adjustments could make them beneficial.

Finally, several recommendations were made for the successful implementation of the proposed measures such as cost benefit analysis. It was also recommended to analyse in greater detail the causes of particularly high overall energy consumption in the building, which is possibly due to high infiltration losses of air-conditioned air through open doors and windows.

Acknowledgments

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List of Abbreviations

ANN	Artificial Neural Networks
AQI	Air Quality Index
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CAD	Computer-Aided Design
CO2	Carbon Dioxide
DCV	Demand Controlled Ventilation
DHW	Domestic Hot Water
EED	Energy Efficiency Directive
EnMS	Energy Management System
EPBD	Energy Performance of Building Directive
EPC	Engineering, Procurement and Construction Contract
EPC	Energy Performance Certificate
EU	European Union
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HCHO	Formaldehyde
HEPA	High Efficiency Particulate Air
HVAC	Heating, Ventilation, and Air Conditioning
IEC	International Electrotechnical Commission
IEQ	Indoor Environmental Quality
ISO	International Organization for Standardization
LED	Light-Emitting Diode
PDCA	Plan-Do-Check-Act
PV	Photovoltaic
SHGC	Solar Heat Gain Coefficient
TOBUS	Tool for selecting Office Building Upgrading Solutions
TRNSYS	Transient Systems Simulation Program
TVOC	Total volatile organic compounds
UV	Ultraviolet
VT	Visible Transmittance

WHO	World Health Organization
XPS	Extruded Polystyrene

1 Introduction

1.1 The need for energy audits

The building industry is recognised as a significant energy consumer considering that approximately half of the energy used in the world is related to maintaining adequate environmental conditioning in buildings. Heating, cooling, and mechanical ventilation account for around two-thirds of this energy.

Evaluation of consumption patterns and identification of specific energy-saving measures are the most important aspects of energy management activities, including energy conservation programmes. These aspects can be accomplished through energy audits.

After oxygen, water, and food, energy ranks fourth on the list of human fundamental needs. So, in addition to efficient use, energy conservation for future generations is required; energy audit and management offers a promising answers in these regards.

Energy audits allow to identify deficiencies in the building's envelope as well as in building energy systems which may require upgrades to achieve higher energy efficiency.

The European Energy Efficiency Directive 2012/27/EU (EED) requires member states to develop programmes that encourage energy savings in SMEs (Small and Medium Enterprises). However, the uptake of energy audits and the implementation of energy conservation measures among SMEs have been low to date.

The SPEEDIER project, funded by the European Horizon 2020 programme, offers an opportunity for energy audit experts to take a new approach by providing SMEs with an outsourced and self-financed energy management service [108].

This energy service will:

- Facilitate the performance of energy audits and the implementation of energy saving measures in SMEs.
- Demonstrate the effectiveness of the self-financing mechanism.
- Improve the energy culture of SMEs through a series of awareness raising and capacity building activities.
- Increase the competences of the main actors in the energy market.

1.2 Building retrofit for energy saving

Renovation of public and private buildings is a necessary step that has been identified in the European Green Deal as a vital project for driving energy efficiency in the sector and meeting goals.

Building renovations can also play a critical part in European economic recovery following the COVID-19 epidemic, given the labour-intensive character of the construction sector, which is mostly dominated by Maltese firms. To jump-start the recovery, the Commission's recovery plan provides additional funding for EU building upgrades.

To achieve this twin goal of increased energy efficiency and economic growth, the European Commission announced the policy "A Renovation Wave for Europe - Greening our Buildings, Creating Jobs, and Improving Lives" [109] in 2020.

Buildings in the EU account for 40% of energy consumption and 36% of greenhouse gas emissions, owing to their construction, use, refurbishment, and destruction.

To meet the EU's 55-percent emission-reduction objective by 2030, it is anticipated that the union would need to cut construction emissions by 60%, final energy consumption by 14%, and heating and cooling energy consumption by 18% (all compared to 2015).

Given that 75% of EU buildings are inefficient, the commission plans to adopt legally enforceable minimum energy performance requirements in 2021 to provide legal certainty to public and private proprietors and renters.

1.3 Building A Case Study

The facilities under study belong to a law firm in Valletta, is a typical historic building in Valletta which mainly consists of offices. Its configuration is complex, divided into 5 floors and has two entrances to the outside.

1.3.1 Environment and location

The office building under study is in the centre of Valletta, the capital of Malta.
In Figure 1 the location in which the office building stands in Valletta, is indicated.

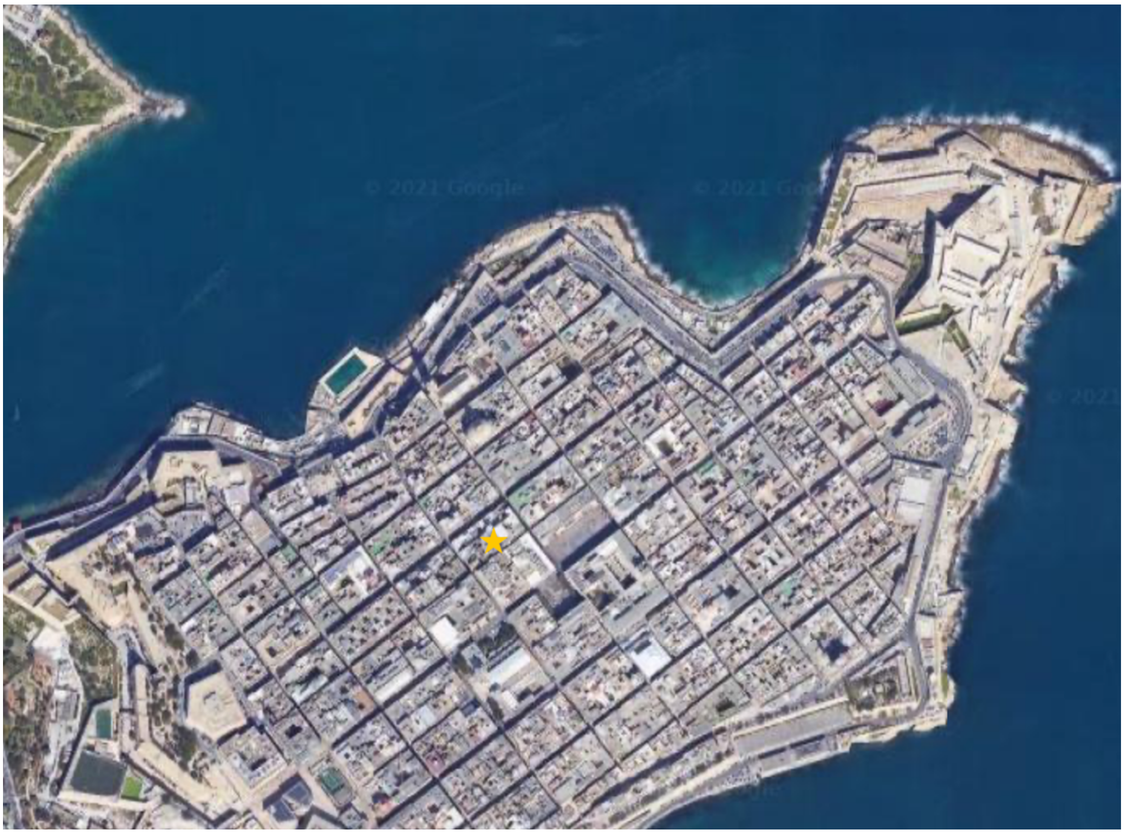

Figure 1. View of Office Building Location in Valetta [64]

The coordinates of the building location are 35°53’56.8”N 14°30’44.6”E. Its main entrance is from 171, Old Bakery Street, having another one in the much narrower Strait Street [64]. It is abutting other buildings on both sides. The site is around 52 meters above mean sea level [65].

A closer view of the office building studied can be seen in Figure 2. A glazed internal yard is shown in the centre and a rooftop solar photovoltaic system is also seen to the south-east of the building.

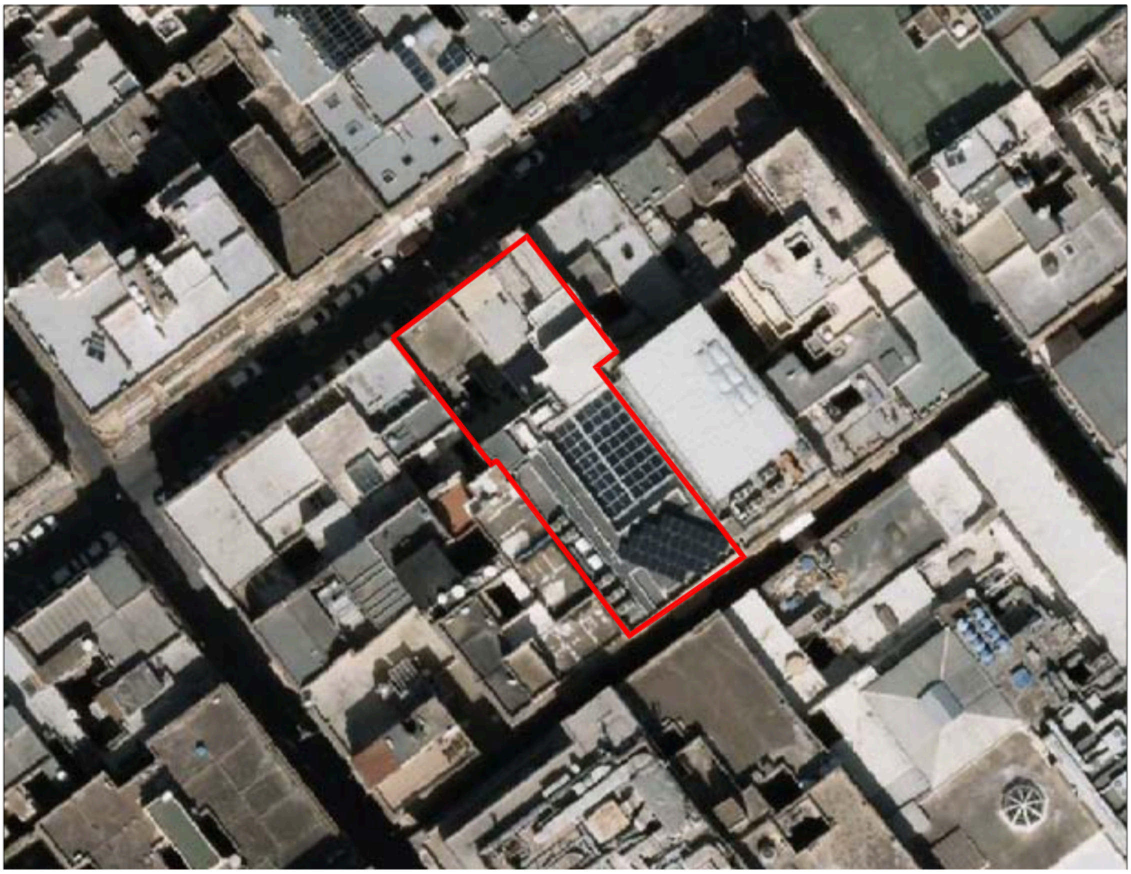

Figure 2. Office building perimeter view

1.3.2 The Maltese climate

The climate in Malta is Mediterranean, i.e., it has hot, dry summers with an average temperature of 25°C and highs reaching an average of 33°C and occasional peaks of up to 37°C. Winters are mild and rainy with an average temperature of 14°C but at high wind speeds the wind chill could make the temperature feel like being in single digits, but rarely below freezing [63].

The hottest months of the year are between June and September and the coldest are from December to April. May, October, and November have a milder climate with average temperatures of 19°C, 20°C and 17°C, respectively. Rainfall in Malta is low, averaging

450 mm annually, with the wettest months being October to March and July being the driest month of the year [63].

In Figure 3 one can observe a graph showing average temperatures and volume of precipitation in Malta by month.

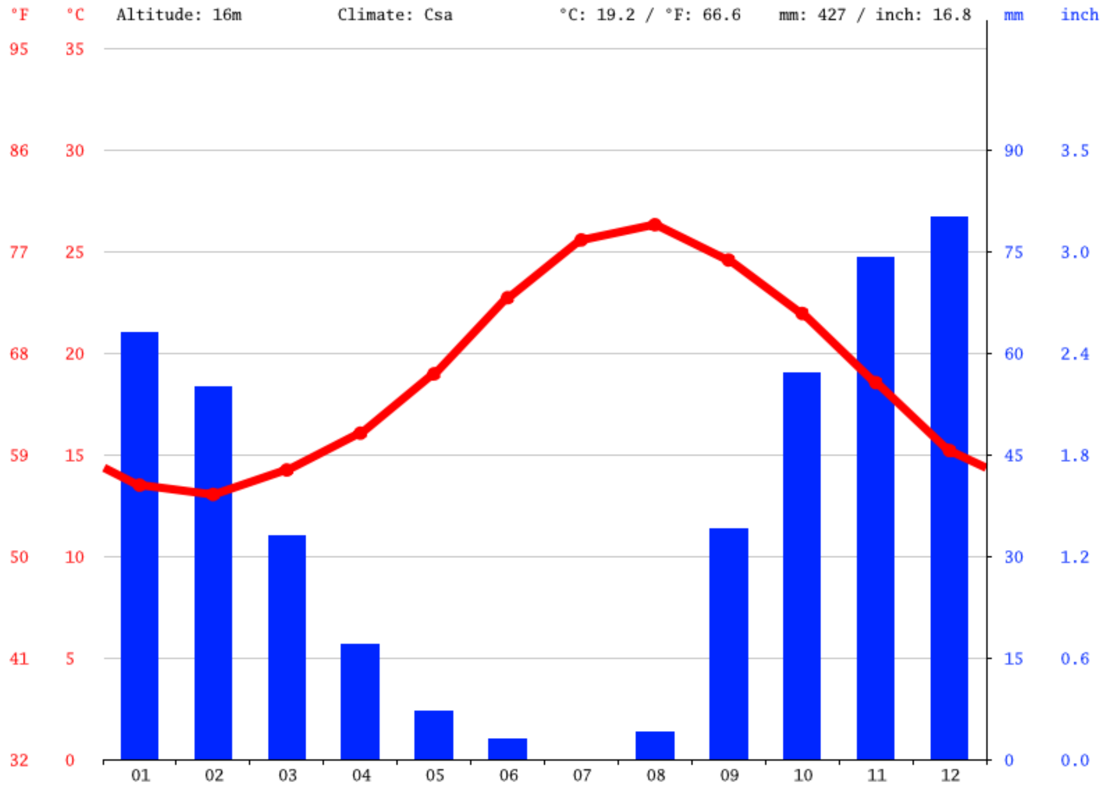

Figure 3. Average temperatures and volume of precipitation in Malta by month [90].

With regards to solar energy, Malta receives an average of 5 kWh/m²/day on the horizontal making it Europe's highest. This is one of the main causes of overheating in buildings either because of ingress through glazing or overheating of walls and external roofs [89].

1.4 Aim and objectives

The aim of this dissertation is to carry out an energy analysis of a medium-size office building by modelling it using a simulation software to maximise the energy efficiency of the building.

An energy audit of the building under study was completed in November 2012, and it focused on energy use, and lighting, as well as investigating the possibility of integrating renewable energy sources. Data was collected on all electrical equipment for this reason, and the study resulted in several proposals for energy improvement, such as lighting changes, consolidation of printing and photocopying services and timers for water dispensing devices [88]. However, it did not delve into the quantification of savings if energy efficiency measures are applied to the building envelope, such as insulation and shading or when certain measures are implemented, such as introduction of desk lamps instead of general lighting in rooms. Therefore, in this project, the building envelope and energy services will be evaluated in particular.

Consequently, the main objectives of this dissertation are to:

- Analyse the constructive characteristics of the building in order to identify possible improvements.
- Evaluate the results of the simulation to get an overview of energy consumption.
- Identify whether the proposed improvements produce significant improvements compared to the current situation.

1.5 Dissertation structure

The Dissertation is composed of 5 Chapters. Chapter 1 gives an overview of the need for energy audits and what the EU states about them, provides a background on the location of the building under study and determines the aim and objective of the project.

In Chapter 2 a literature review will be made covering the main points of research in energy analysis, efficiency and regulations.

Chapter 3, presents the methodology where the approaches used for this project are made, essentially branching into two components such as the walk-through audit to identify on site issues, measure certain parameters linked to the indoor environment such as lighting levels and carbon dioxide concentration levels and determine the characteristics of the building and the second one is the modelling of the building and the application of possible effective energy efficiency measures.

Chapter 4 explains and analyses simulation results for the measures proposed to determine whether it would be feasible and beneficial to implement them.

Chapter 5 provides a general synopsis of the outcome resulting from the simulation of the measures proposed as well as several recommendations for future work.

2 Literature Review

2.1 Definition and Aim of an Energy Audit

An energy audit focuses on providing a technical report detailing the appropriate measures for an adequate and rational management and use of energy. It should be considered that in the case of tertiary or industrial buildings, such improvement measures should not affect the quality of service or the productivity of a company, and in the case of residential buildings, they should not interfere with the habitability of a building [1].

The final objective of an audit is on one hand to provide more effective measures to rationalise energy consumption and on the other to be able to optimise the procedures and processes of a given activity that involves the use and consumption of energy, so it will [1]:

- Obtain information on energy invoicing to be able to analyse the consumption history of energy-consuming resources.
- Carry out an inventory study and analysis of all the machines, motors and equipment that consume energy, as well as all the energy installations and the building's thermal envelope using thermographic cameras to quantify, analyse and classify energy consumption.
- Based on this study, identify those zones or areas likely to achieve the greatest energy savings.
- Make suggestions and recommendations to increase the building's energy efficiency.
- Quantify the energy and economic savings to obtain the payback periods for the different improvement measures proposed.
- Analyse and study the tariffs offered by energy companies and propose recommendations.
- Propose measures for an adequate management of water use.

The main advantage in the case of organisations and companies is the positive impact generated by reducing production costs and, at the same time, improving business competitiveness.

Another way of carrying out an energy analysis of the building is to model the building using a modelling software and analyse the impact on energy consumption when certain energy efficiency measures are applied to it. The majority of energy consumption in buildings is caused by air conditioning, space heating, lighting, water heating, and ventilation, while small equipment such as photocopiers, fridges, and laptops are typically not considered for this exercise as energy share of plug-in appliances is usually small compared to the total energy consumption.

This method of energy modelling and analysis forms the basis for designing new buildings and for analysing potential renovation measures in existing buildings. It is also the method used for the EU Energy Performance of Building Directive (EPBD) 2018/844 [34].

2.2 Scope of the Energy Audit

The scope of the Energy Audit should be defined jointly between the representatives of the institution, in which the analysis is carried out, and the auditor. In the scope the following points are commonly defined:
- Which area / buildings?
- Which uses / applications?

From these points it is possible to adequately dimension the audit in terms of time and resources needed, as well as to ensure that the work to be carried out meets the expectations/requirements.

In this regard, it is worth noting that an audit, as an evaluation tool, should be of great interest to the firm, as it allows it to evaluate the levels of efficiency and effectiveness with which they perform; it provides them with reliable information; it helps to identify possible risk factors that could jeopardize future activities; and it allows them to know the company's degree of compliance with the current regulatory framework, among other advantages [8].

2.3 Auditing and Energy Efficiency

2.3.1 Energy efficiency

According to the EU Energy Efficiency directive ‘Energy efficiency means the ratio of output of performance, service, goods or energy, to input of energy.’ [11]

Energy efficiency therefore refers to the optimisation of energy consumption, seeking to reduce energy use while producing the same or better results. Efficiency is a concept that affects all human beings, since everyone needs energy to carry out an activity, be it individual, collective, commercial, industrial, etc. Energy users must conserve energy to decrease costs and ensure financial, political, and environmental stability.

Energy is one of the current issues for industry related and commercial users that want to boost efficiency and so maximize their profit. The audits should follow European or international standards such as ISO50001 and be carried out by professionals. Audits should follow a set of rules, allow for calculations to give clear data on potential savings, and be able to be saved for analysis and performance tracking.

2.3.2 Key aspects to promote efficiency

Energy policies are a necessary instrument to encourage the development of efficiency worldwide. Aspects to be considered are [17]:

Energy mix diversification: to reduce dependence on the outside world and to give more weight to fewer polluting energies such as renewables.

Price signals: adjusting energy prices to give the right signals to consumers, while maintaining incentives for behavioural changes or the purchase of more efficient equipment and technologies.

Encouraging the use and development of new technologies: To establish a creative and competitive industrial and service sector, incentives are required to stimulate the development and adoption of new technology.

2.3.3 Relationship between auditing and energy efficiency

The cost of energy is one of the most important factors in the total costs of operational processes. Adequate energy consumption allows companies to achieve greater productivity and quality in their production as by reducing electricity costs, the funds saved could be allocated to other sectors.

For this reason, knowledge on how the company contracts its energy, how it consumes it in its processes, how much it affects its costs, its relative position compared to other similar companies and the possible improvements to reduce energy costs are fundamental aspects in the economic and productive optimisation of industries.

By carrying out the audit, a sufficiently reliable knowledge of the energy consumption of the industry is obtained, detecting the factors of its energy consumption, and identifying the possibilities of saving. The aim is to optimise the value of the energy bill through the study of total consumption and per unit of production [17].

There are several reasons for implementing energy efficiency measures in a company

- Legislative developments such as EU and national requirements for energy efficiency
- Commitment of the company management to sustainability
- Seeking cost savings on energy bills
- Reducing greenhouse gas emissions into the atmosphere
- Gaining competitive advantage
- Seeking to improve the company's image in the eyes of its stakeholders
- Customer demands
- Institutional and stakeholder pressure, including public opinion
- Access to subsidies and incentives for energy savings

2.3.4 Impact of COVID-19 on energy efficiency in office buildings

The Coronavirus 19 pandemic has brought numerous changes on different aspects of life, including the use and operation of office buildings. To mitigate the virus propagation, different measures have been implemented in workplaces such as incentivising remote work or increasing ventilation and air flow in indoor spaces.

Apart from extensive cleaning, ventilation constitutes the best non-medical action to take to prevent COVID-19 from spreading. The World Health organization (WHO) urges workplaces, schools, and tourist spaces to increase fresh air intake or filter the circulated air. These ventilation related measures can be differentiated in two groups:

Active: Ensuring adequate fresh air intake according to established standards such as the EN16798-1 standard [82] or filtering recirculated air with the help of effective high efficiency particulate air (HEPA) filters and ultraviolet germicidal irradiation (UVGI), also known as far UV-C light (222 nm) [83] that is installed in the air ducts to kill viruses.

Passive: Limiting maximum room capacity, keeping distance, and providing natural ventilation.

According to N. D. Cortiços and C. C. Duarte [18] taking the passive measures approach in US high-rise office buildings with “warm-dry” to “very hot-humid” climates, the usable energy consumption has decreased on average, by 11.92%. This is mostly related to changes in air circulation and air supply from the exterior per person/area (that allows for free cooling), as well as air recirculation decrease and DCV disabling, which forces continuous external airflow. Also, as reported by ASHRAE’s Recommendations for COVID-19, the main factor causing this decrease is a higher person/area rate which facilitates constant air flow. These measures allow for a lower cooling demand.

2.3.5 Energy audits in areas with a similar climate

Studies of buildings in a similar climate to Malta generally conclude that the best way to improve energy efficiency and minimise electricity costs is to maximise the use of daylight and natural ventilation [22], [23], [32]. The focus was mostly on using more energy-efficient equipment, improved equipment management, indoor air quality, and human behaviour. For example, one of the measures taken in Japan was the ‘Cool Bizz’ a campaign in which companies allowed employees to wear casual clothes and setting the inside temperature at 28°C to save energy consumed by HVAC in summer [23]. Another measure taken in one audit was cleaning lamps and luminaires and promoting the maintenance of facilities to maximise their efficiency [22], while in an Office building in Iran, one of the solutions taken was to reduce energy consumption was to retrofit horizontal shading for windows and to remove internal blinds [32].

In Mediterranean regions, one of the most important factors that needs to be considered is to reduce solar overheating. Koç and Maçka Kalfa, studied the benefits on energy savings when using fixed external shading devices of different natures for office buildings in Mediterranean climate regions. The analysis was also made by comparing shading with high and low performance glazing. Energy consumption was calculated to reduce 40% for low performance glazing and 75% for the high performance type [43]. Of course, such figures would also depend on factors such as the window to wall ratios and the orientation of the building. Therefore, it cannot be taken as given that such high savings will always be possible to achieve. For the case of Malta, saving would generally be lower for offices, because many of them are part of a larger building, which means that at least one side of the building will have no glazing or at most small apertures that overlook narrow shafts and therefore are automatically shaded for most of the year.

An audit carried out in an educational building in Madrid, in the centre of Spain, where temperatures are slightly lower than in Malta, revealed that replacement of the windows (U-value of 5.7 W/m²K) with high efficiency ones (U-value 1.6 W/m²K) was the most cost-effective option. This was found to save the most energy on seasons with lower temperatures, reducing significantly heat losses through the windows. This conclusion was found by calculating the payback times for the improvements needed to increase the levels of thermal envelope. The analysed building was simulated, and an economic analysis was conducted afterwards [51]. It is to be noted that notwithstanding the fact that window replacement was identified as the best option, the actual payback period was found to be 22 years, meaning that for such a recommendation fiscal support from government should be considered, if offices are to be encouraged to renovate in line with EU decarbonisation efforts.

On the other hand, in countries with a colder climate energy is mostly consumed for heating purposes. Therefore, insulation of walls, floors and roofs take priority for retrofitting and would generally produce higher energy benefits that insulating the glass apertures only. For example, it was demonstrated that only roof insulation could save up to 30% on energy consumption. Triple glazed windows were another option considered, with a much lower benefit of 9% of energy conservation. [24]

2.4 Types of Energy Audits

Depending on the requirements and specifications of the energy audit in terms of depth, size, type of industry, three types of energy audits can be considered [2], [3], [4].

2.4.1 Walk through energy audit

The Walk Through energy audit is a preliminary analysis in which the auditor examines energy consumption in a short period of time. An identification of areas for attention and improvements would be made so that the organization is provided with a general analysis of energy consumption and its major problems are displayed. This way, immediate improvements can be offered., such as troubleshooting for maintenance, identification of operational problems or determination of equipment deficiencies.

Atiba et al. carried out a walk-through energy audit in Nigeria to reveal cost-effective solutions such as scheduling motor operations, turning off air conditioners when no one is present, and switching to LED lighting. The process was conducted by going to workplaces, workshops, and laboratories to gather data on energy usage to get a reliable approximation of daily consumption. To successfully use the air conditioner inside every defined space and operation hours, the envelope should then be highly sealed from heat gains, with better building insulation [70].

2.4.2 Targeted energy audit

Based on the results obtained in the Walk Through audit. The targeted audit offers a more detailed evaluation on a specific target. Its methodology can vary depending on the type of industry analysed (commercial, industrial, residential). The result is an enumeration of actions suggested to be taken. Its scope can also include an interview with the people involved. It is relevant to specify that the coverage of this audit is just the targeted area.

A company may, for example, focus on the boiler, lighting, or compressed air systems to save energy. This type of audits entails extensive surveys of the studied subjects/areas, as well as a study of the energy flows and costs related to those objectives [71]. Al-Qawasmi and Tlili performed a targeted energy audit on the air-conditioning system to look for alternatives to improve energy efficiency in a government building in Saudi Arabia as air conditioning accounts for 60% of energy consumption in the building. After the analysis, alternatives were provided such as adding a Stirling Engine to the Air Conditioning Cycle [72].

2.4.3 Detailed energy audit

A detailed energy audit can be understood as the verification, monitoring and analysis of energy use and its consequent technical report with an action plan to reduce energy consumption. It therefore goes beyond quantitative estimates.

After the walk-through energy audit, this sort of energy audit is usually conducted. It calculates energy efficiency, real energy consumption and losses, using advanced measurement tools such as temperature loggers, flow meters, electricity analysers, and infrared scanners, besides others.

An energy balance (energy use description) and a set of measures to save energy based on the building's data are among the outcomes of the thorough energy audit. Each measure may also include an economic analysis of the results, which helps to categorize and prioritize their adoption.

2.5 Applicable Standards for Energy Audits

2.5.1 ISO 50001:2018. Energy management systems — Requirements with guidance for use

The ISO50001 standard for corporate energy management is the most commonly utilised in the world. The ISO 50001 certification of an Energy Management System (EnMS) assists enterprises in implementing an energy strategy and correctly managing energy elements originating from their activities, such as services, buildings, goods, and so on, resulting in actual and demonstrable energy cost reductions. ISO 50001 gives you the tools you need to figure out which activities use the most energy and are causing a "energy and economic leakage." Organizations implement a plan of action to reduce the energy consumption of their own facilities and systems in an integrated way while increasing their energy efficiency after the problem has been discovered. The Energy Management system (EnMS) is based on the PDCA (Plan-Do-Check-Act) cycle represented in Figure 4

Figure 4. PDCA Cycle (ISO 50001:2018)

This standard can be utilized on its own; however, a company can choose to connect their EnMS with some other management systems or use it to achieve other commercial, environmental, or social goals. Two firms that undertake comparable activities but have varying energy performance can both meet the ISO 50001 criteria.

The efficient implementation of this paper presents a logical plan for increasing energy performance that may influence how businesses manage energy. By incorporating energy management into business strategy, companies may develop a mechanism for continual quality improvement of energy efficiency. [52].

2.5.2 ISO 50002:2014. Energy audits - Requirements with guidance for use

Users of ISO 500002 are urged to look for improvement possibilities in a variety of areas, including operating and maintenance controls, changes, and infrastructure investments. The audit's findings include data on current consumption and productivity, as well as graded suggestions for improving energy efficiency and financial advantages. This standard helps companies to assess the financial advantages of energy-saving options over their expected lifetime. The procedure criteria for conducting an energy audit in terms of energy productivity are described.

ISO 500002 does not include the parameters for selecting and evaluating the competence of entities offering energy audit procedures, nor does it address an institution's energy management system auditing, both of which are covered by ISO 50003. [53]

2.5.3 ISO 50003:2021. Energy management systems — Requirements for bodies providing audit and certification of energy management systems

This annex is intended to help audit and certification organizations by laying forth standards for ensuring competence, consistency, and neutrality for these processes.

This is usually considered in conjunction with ISO/IEC 17021 – a set of prerequisites to allow professional entities to undertake certification of management systems; it adds extra energy-based specifications to the audit planning stage and seeks to guarantee that audit personnel have the necessary skills [7]. In particular, it discusses the prerequisites for the auditing. It includes the planning stage, the preliminary certification audit, on-site auditing, auditor competency, audit period, and multi-site testing.
[54].

2.5.4 Energy Efficiency Directive (EU) 2018/2002

The EU Energy Efficiency Directive (EED) 2018/2002 amending Directive 2012/27/EU [33] where countries are urged to implement plans to promote development of energy audits in small and medium-sized enterprises and make them compulsory for large companies, adds an expansion to the energy savings obligation in end use included in the 2012 directive. Savings of 0.8% on total energy would have to be reached by countries each year excluding Malta and Cyprus, which would have to save 0.24% annually [11].

Customers will be able to better understand their heating bills and gain vital information on energy consumption thanks to stronger requirements on metering and invoicing of thermal energy under this Directive.

Also, national normative accessible to every citizen on costs of cooling, heating and hot water usage in apartments and other purpose buildings are also imposed on EU countries. It also calls on new energy systems to keep an adequate level of energy efficiency. [11]

2.5.5 Renewable Energy Directive (EU) 2018/2001

The following three section expand briefly on the main energy directives of the EU that have a direct link or impact on energy efficiency in buildings. The first one is the Renewable Energy Directive which establishes a binding overall EU target for 2030 and requires that Member States declare a target that is commensurate with their capacities to use renewable energy and increase its share beyond that set for 2020. The National Energy and Climate Plan lays out the national goals, which include renewable energy in transportation. [15].

The Directive also establishes standards for statistical transfers among Member States, cooperative projects between Member States and foreign countries, origin of energy guarantees, administrative processes, information and training, and renewable energy grid access. It also establishes requirements for biofuels and bioliquids' long-term viability. [15]

2.5.6 Energy Performance of Buildings Directive (EU) 2018/844

The second energy-related directive is the European Union's newest update to the Energy Performance of Buildings Directive (EPBD) 2018/844. By reaching the energy efficiency targets established for 2030 to cut greenhouse gas emissions, boost the percentage of renewable energies in buildings, and achieve energy savings, the European Union hopes to create a sustainable, competitive, safe, and decarbonized energy system.

One of the Directive's main requirements is that Member States must define a long-term strategy for buildings restoration as a target for their decarbonization by 2050, which will establish a roadmap with the necessary measures for its implementation. The primary focus is on the 15% worst energy performing buildings, which needs to be identified through statistical analysis of energy performance certificates of national databases and carry out specific actions for different building categories to improve their rating to be at least in conformity with the minimum energy requirement as defined in the national code. For the case of Malta, this is called Technical Document F [84]. It also defines the most appropriate financing options that Member States can consider to help meet the objectives set. For example, existing inefficient buildings undergoing significant restoration should be supported with high efficiency alternative equipment, when possible, technically, functionally, and economically. Moreover, these buildings should meet the appropriate climatic and fire safety conditions.

In new buildings, where technically and economically feasible, high-efficiency installations should be promoted to provide good indoor climate and safety conditions, as well as improvements to be made to the building envelope and the installation of renewable energy systems onsite or in nearby areas such as in community garages of the building. In fact, new buildings must achieve nearly zero energy status as defined in the minimum energy requirements, which for the case of Malta are defined in Technical Document F.

In December 2021, the EU has also published a proposal for the recast of the EPBD 2018/844 [35]. The primary goal of this update is to minimize greenhouse gas (GHG) emissions (reduction of 55%) and final energy demand in buildings by 2030, and to develop a sustainable building plan to reach climate neutrality by 2050. The effort focuses on many aims to accomplish this reduction, including boosting the rate and depth of building restorations, enhancing energy management and architectural sustainability reports, and guaranteeing that all structures meet the 2050 climate neutrality standards. Increased financial aid, modernisation, and interoperability are all drivers for attaining these objectives.

Some of the changes made were requiring new buildings to be zero-emission rather than only near-zero and also transforming the existing ones into zero-emission by 2050, establishing minimum energy performance standards to facilitate energy improvements in existing buildings, ensuring adequate conditions in buildings like optimal air quality, as well as new requirements for building passports and higher accessibility for users to building data.

An innovative initiative of the EU EPBD 2018/844 to accelerate decarbonisation is the introduction of the building passport (Pas-E). This is a voluntary scheme forming part of the set of political proposals of the Green Deal or European Green Pact, promoted by the European Commission. Its goal is to increase the quality of refurbished buildings with an integral vision, to improve living conditions and reduce the environmental impact throughout the whole cycle. It is, therefore, an individualized plan for each building that holistically considers the three areas related to the improvement of habitability: technical quality of the construction systems and installations, functional quality of the dwellings and efficiency in the use of resources, especially energy and water.

In Figure 5 the Building Renovation Passport procedure is shown. It involves a set of input parameters that are processed and produce mainly three outputs, namely, a document that has all the relevant information, database, and characteristics of the building, a comprehensive energy audit and recommendations for energy efficiency measures and a circular interaction between further energy audits and more energy efficiency improvements which would eventually bring the building closer to carbon neutrality.

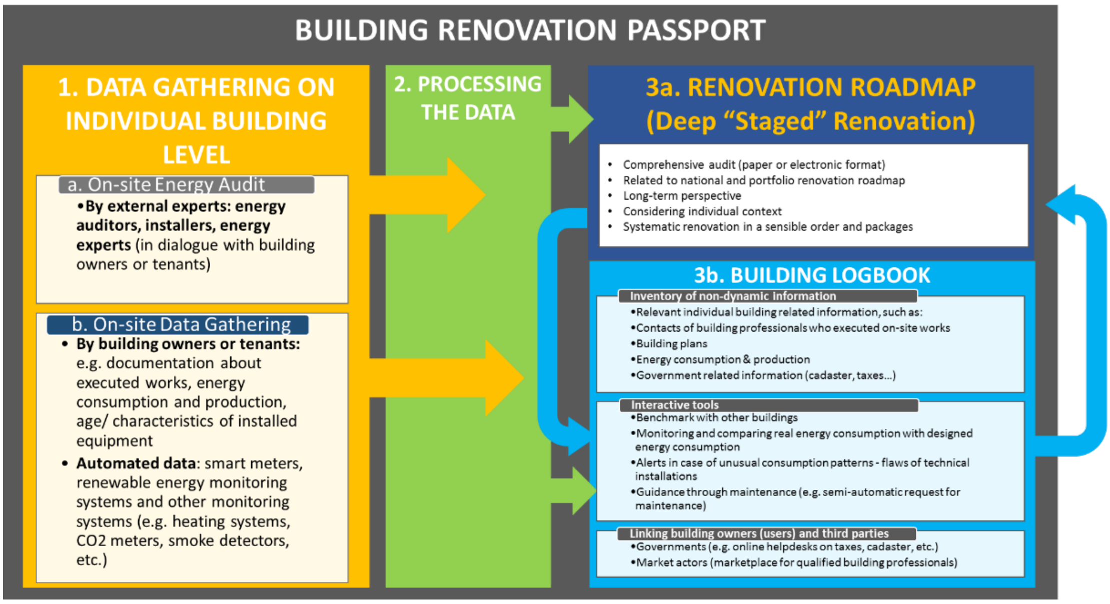

Figure 5. Building Renovation Passport – a summary of its features (source: BPIE).

2.5.6.1 Other Building Renovation passports

The use of building passports is not new to Europe. For example, the "woningpas" is a digital passport that was set by the Flemish Government in 2018 and is applicable to every building in Flanders. The passport is accessible to the owner of the building and third parties that are granted access [66].

Also in France, there is the French "Carnet numérique d'information, de suivi et d'entretien du logement", which is a secure online service that will, above all make it possible to improve information for all the parties involved in a dwelling i.e., the owners, the buyers, and the occupants.

This digital logbook will allow one to:

- Know the state of the dwelling and the building,
- Know when the dwelling is subject to the status of co-ownership,
- Know the functioning of the equipment of the dwelling and the building,
- Support the improvement of the energy and environmental performance of the building and the dwelling for the whole life of the building [67].

It is a measure introduced by the Energy Transition Law for Green Growth of 18 August 2015. This booklet is already mandatory for new homes for which the building permit was submitted after 1 January 2017. It will be compulsory for all housing transferred from 1 January 2025 onwards [68].

A third example from Germany is the “Eigenheim Manager”, which is an internet program that assists building owners by logging information and assisting in the achievement of certain objectives within the building. By displaying information in a comprehensible manner, the app may be used to minimize usage, expenditures, or as a maintenance manual [69].

In summary, it is clear that energy audits are going to play a more important role in the EPBD through the building energy passport and therefore it is no longer sufficient to carry out a routine EPC that is normally used for selling or renting a property. On the other hand, the EPBD is also stressing that EPC software needs to be updated and preferably be based on hourly simulations of the building, in a bid to make the results more realistic and get closer to actual standard energy consumption for the different categories of buildings. This justifies the approach of this dissertation to analyse the outcome as amply explained in the aims and objectives, as well as in the methodology chapter.

2.6 Energy Efficiency in Malta

Malta has been through a notable rise economically and population wise. Its economic growth rate has averaged 1.8% per year between 2010-2018, the second largest increase in the European Union. Coupled with the rise in the real estate market and in tourism, this has led to an increment in energy consumption. Moreover, Malta has attracted several new commercial sectors that can be categorised as soft industries such as gaming companies, banking, offshore services, besides others, which are all mainly based on operation from offices or office-like establishments, mostly using electrical resources. Therefore, the attention to be given to offices in terms of energy efficiency is becoming more relevant today [10].

Malta's energy consumption has increased by 18% in the previous four years, with peak demand expected to rise from 445MW to 538MW in the following six years [21].

Because of shore-to-ship power projects, automobile electrification, and the economic recovery brought on by the COVID-19 epidemic, electrical demand is expected to rise.

Figure 6 shows the sectoral energy consumption in Malta in 2018, half of the energy is consumed in transport; this is related to the elevated use of private cars and the low percentage of people taking public transport [20]. The services sector (tertiary and others) is second in place as it is the main part of Maltese economy.

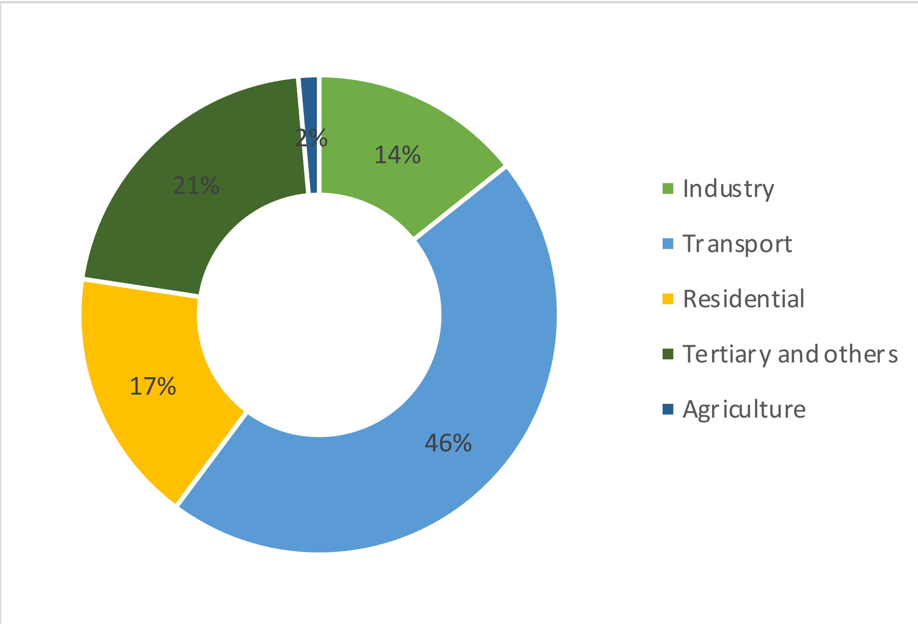

Figure 6. Energy consumption in Malta by sector in 2018 [13]

Romania and Malta share the lowest inland energy consumption per capita in 2018, i.e., 2 toe/capita due to an economy based on the services sector. Because of the lack of a railway system, road transport is the principal mode of transportation in Malta. Moreover, Malta is an island, and this adds more challenges to transport as travel can only be made by sea or air. Most of the population in Malta lives now in apartment buildings; this is related then to an increase in air conditioning and heating usage [13].

Despite low consumption levels per capita, Malta's electric grid and market have distinctive features, including the small size, the presence of a single electricity distribution company, the absence of district heating and cooling systems, and the small size and number of suppliers and industry stakeholders, which limit the number of energy efficiency measures that can be taken and adversely affect competitive price availability in the market.

As mentioned above, urban expansion and GDP growth have made it more difficult to reduce energy use in recent years. Nonetheless, after 2020, Malta's energy efficiency initiatives will attempt to reach reductions cost-wise on energy in important sectors while also considering the effective potential. Malta will aim to lower its economy's overall energy intensity and satisfy its responsibilities under the European Union's Energy Efficiency Directive 2012/27/EU, according to the National Energy and Climate Plan (2021-2030) [13]. This will also be substantiated by the approved second electricity interconnector to mainland Europe as well as the planned hydrogen/natural gas pipeline, to Sicily, Italy [21].

2.7 Different Techniques for Energy Analyses: Energy Audits

Analysing a building through an energy audit can help identify which elements or places produce the highest losses on energy depending on the climate and purpose for which the building is used. Karagiorgas and Tsoutsos [36] carried out a simulation on various energy audits for hotels in Greece and produced a model for representing the energy trends in these buildings based on the analysis made.

In another study and based on data obtained in the energy audit of several Hellenic bank branches, Spyropoulos and C. A. Balaras [37] concluded that most of the offices were already provided with latest generation equipment. Furthermore, it was difficult to reduce standby energy usage, and as a result, possible energy savings from equipment could not be considered. Therefore, the main energy saving measure resided in modifications to the building envelope like double glazing windows. Thanks to an envelope analysis and a computer program developed by Al-Ajlan [38] it was demonstrated that insulation material had the greatest impact on transmission loads and R-values, whereas wall layout had the least impact. In this way the audit contributed to better decision making.

Kofoworola and Gheewala [39] analysed a typical office building in Thailand, through an audit; it was discovered that air conditioning accounted for almost 60% of energy consumption, as shown in Figure 7 below for typical offices in tropical climates. Also, in this case, the centralised setup of the air conditioning system did not allow for any individual settings or controls in the different rooms, leading to major losses on energy savings.

Figure 7 shows an example of energy consumption in a typical building energy consumption in Tropical countries [19]

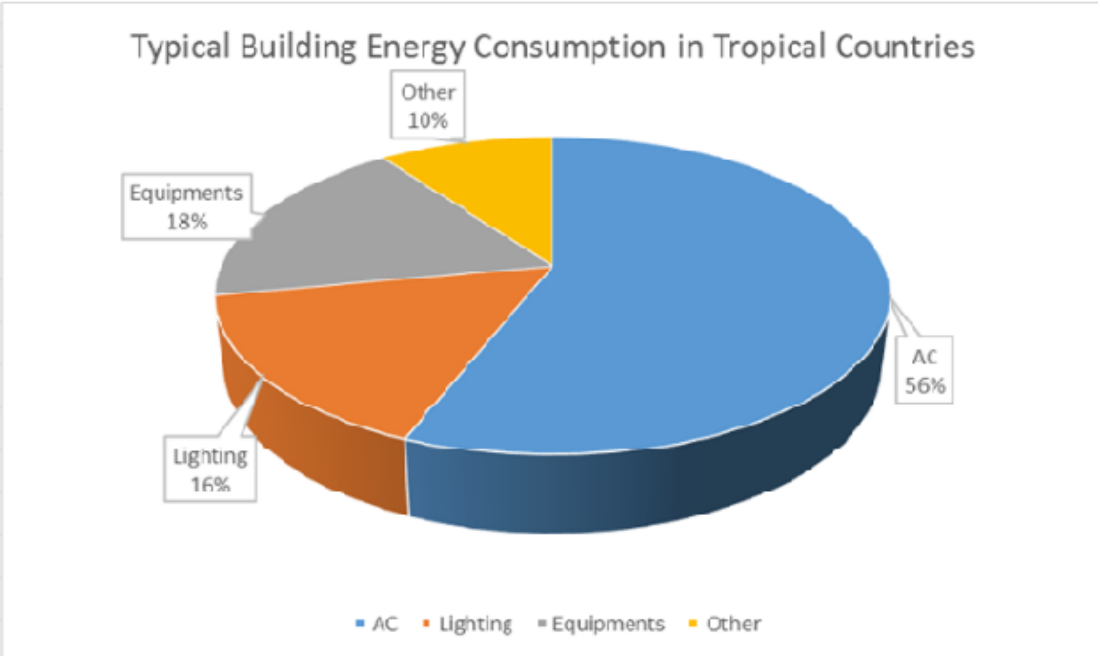

Figure 7. Example of typical office building energy consumption in tropical countries [19]

Thanks to an energy audit in an educational building, Aljmi identified energy saving options as retrofitting and no retrofitting depending on whether they had a cost burden or not. Non retrofitting measures produced savings of 6.5% yearly on the building while the retrofitting ones decreased almost 50% of yearly energy consumption. In the audit it was also discovered that the building was managed poorly, influencing directly on work productivity, and of course producing energy wastage [44].

2.8 Different Approaches for Energy Analysis: Statistical Analysis and Modelling

Determining which measures will demonstrate to be the most successful on energy saving is a challenge. With such a great variety of options, biological, economical, energetic, and social issues should be considered when making decisions to carry out a correct diagnosis and maximizing energy efficiency while reaching optimal user demands [45].

2.8.1 Decision-supporting methods

This strategy is based on using multicriteria-based decision-making methodologies, to aid in the ultimate decision-making process [45].

Blondeau et al. use multicriteria methods to assist in establishing the appropriate ventilation plan for a university building, ensuring the highest air quality inside, determining the optimal temperature for users, and reducing energy consumption. Depending on pre-determined criteria, they rank the measures from best to worst [46].

To select the most viable renovation measures on a restoration project, Alanne presented a multicriteria "knapsack" model. A utility score is assigned to each of these measures based on parameters. All the utility scores are then utilized as values in a knapsack optimization model to determine which ones should be carried out [47].

Artificial neural networks (ANNs) are non-algorithmic, non-digital, and highly parallel information processing systems. They analyse previously collected data to discover the link in input and output variables. An ANN is similar to a biological neural system in that it is made up of layers of parallel electronic components called neurons. A vast number of weighted linkages connect the neurons, allowing impulses or information to travel across. In general, a neuron accepts inputs through its incoming connections, integrates them, conducts a non-linear operation, and finally outputs the result [85].

To improve the building energy audit process and reduce the time and costs associated with conducting a comprehensive physical assessment, Deb [50], creates prediction models to figure out how much energy office buildings can save. Linear regression and artificial neural networks are used to create these models (ANN). The input variables for the two energy-saving prediction models are chosen using an extensive variable selection process. The results reveal that the ANN prediction model can accurately anticipate the energy-saving potential of a building with a 14.8 percent accuracy.

Multicriteria approaches have the drawback of being applied to a collection of specified and pre-made potential options. If just a small proportion of these solutions are described, there is no certainty that the final option will be the optimum [45].

2.8.2 Data-based methods

Smart meter data-based approaches analyse energy consumption data in short intervals, supplementing energy analysis profile and diagnostics to deliver process opportunities. However, they have several challenges, including:

- The need for training data to generate the model.
- Being specific to a single building and might not be relevant to other similar buildings.
- Absence of a physical justification for some performance characteristics.

In another approach, professionals can use regression methodological approaches to available data and inverse solving techniques to calculate energy consumption of structures with fewer variables, and regression methods can be applied to already existing data to provide further analysis from energy usage data. The model, on the other hand, does not represent the dynamics of the combined impacts of energy conservation measures, which is a key flaw of this method. For example, artificial lighting upgrade would be a case of a combined effect. Renovating the lighting luminaires not only saves energy for lighting, but it also lowers the cooling load, also producing savings on space cooling [49], [50].

2.8.3 Simulation modelling

The most popular and successful way to determine possible energy savings is building simulation. It models the behaviour of a building to determine its energy parameters, and this allows the achievement of possible savings at pre-design, at design, post-design, and operational stages, as well as serving refurbishment or renovation approaches to be assessed prior to implementation. Moreover, simulation facilitates accurate economic analysis of all different options beforehand. [48]. This can be carried out because energy simulation makes it possible to obtain consumption, energy, and production data to improve the understanding of factors that produce variations on energy indices of an installation and predict potential savings.

Reduction on energy costs can be achieved in several ways:

1. Improvements to the building envelope (insulation, shading, double-glazing)
2. Improvement to building services efficiency (better efficiency of heating and cooling systems, water heating, lighting)
3. Introduction of smart controls (timers, motion sensors, reduction of peak load times)
4. Implementation of renewable energy systems

In building simulation, usually the consideration of energy efficiency of plug-in loads (refrigerators, freezers, television, computer, washing machine) are not modelled, because quite often these appliances are already efficient given that the EU has a long history of imposing regulations that allow only the most efficient appliances to be sold in the EU market and also because many of these appliances cannot simply be removed from the building, as they are necessary for its proper functioning. Nevertheless, simulation does take into consideration any heat generation due to the operation of such systems indoors.

When choosing building energy analysis software, the application, the number of times it will be used, the user's experience, and the available technology must all be considered in advance.

Table 1 shows some of the most used building simulation software.

Table 1. Different Building Energy Simulation programmes [31], [86].

Building Energy Simulation Program	Application	Open source?
DesignBuilder	Optimises the efficient design of buildings, allowing dynamic simulations of the thermal behaviour of buildings either with passive solutions only or with certain air conditioning systems, all based on EnergyPlus Engine. It allows a detailed evaluation of the natural ventilation of the building to assess its impact on indoor comfort [87].	NO
ECOTECT	Integrates the analysis of energy, water, and carbon emissions, with tools that make it possible to visualise and simulate the behaviour of the building in the context of its environment. It allows meteorological data to be obtained and analysed from anywhere in the world, to obtain bioclimatic diagrams and to be able to propose passive design strategies for buildings and subsequently check and calculate any element previously applied to the building with these variables [25].	NO
ENERGYPLUS	Utilizes detailed building physics for air, moisture, and heat transfer, such as handling radiative and convective heat transfer individually to endorse radiant system modelling and quantification of thermal, lighting, shading, and visual comfort metrics [27].	YES
eQuest	Provides high quality reports combining an assistant (wizard) to design, build and visualize a 3D model, another one to compare different energy efficiency measures and a third one to simulate the building and display graphs and charts [26].	YES
Openstudio	It allows energy simulation from a model created in SketchUp, in a first step the geometric model of the building is created and then exported to OpenStudio, which has the necessary tools to edit the model and simulate it. Used by US. Department of energy [87].	YES

Harmati, Jakšić, and Vatin, attempted to find alternatives to minimize energy losses and demand for reference office buildings. OpenStudio and EnergyPlus were used to carry out the analysis. The study was conducted for a period of one year. They stated that building energy simulation gave a better understanding of energy consumption in each sector, concluding that energy demand reduction is possible by calibrating model properties and mechanical systems [28].

Rahman et al. simulated an office building in Queensland, Australia, i.e., a sub-tropical climate, using DesignBuilder and divided the measures to be carried out into three: Zero investment, with actions like changing cooling and heating set points in the offices; the result was 2.99% of energy savings. Moderate investments saved approximately 12% annually with measures like double glazing windows, while major investments produced a reduction on energy consumption of 27% by replacing HVAC systems. The paper also concluded that these measures can be applied in hot and humid climates that require a high use of air conditioning systems [29].

Buonomano et al. used TRNSYS, a simulation program created by the University of Wisconsin, to simulate 4 different buildings of the University Hospital Federico II in Naples. In this analysis it was found that the building envelope experienced energy losses due to a lack of thermal insulation. The most profitable measure determined was automation, control, and regulation of the air handling unit to work just when people are using each room [30].

A new decision-making interactive tool, TOBUS "Tool for selecting Office Building Upgrading Solutions" was developed as part of a project involving eight Institutions from Europe to assist professionals on audits for existing office buildings and evaluation on possible retrofits [41]. This software works with Windows and features numerous modules, each of which addresses a different aspect of the diagnostic test, such as building characterization, measurements, cost coefficients, analysis of building state physically and functionally, indoor environmental quality (IEQ), energy usage, retrofit scenarios, financial analysis, and report of results. The program also provides extensive databases on the physical condition of deterioration, which include hundreds of drawings, retrofit work details, and cost information, among other things [40].

Rossi et al. studied the energy and economic implications of thermal insulation placed to the exterior side of an existing office building by simulating it on DesignBuilder for calculating energy requirements and assessing the interior thermal comfort index. Findings indicated that hyper-insulation is ineffective in the regions studied (Cairo, Rome, Milan, and Palermo) [42].

2.9 Summary

This chapter has shown that the Energy Efficiency First principle is being systematically implemented in all of the EU Energy Directives. In order to achieve this aim and the forecast decarbonisation targets for Europe, all Member States have to share the burden through the implementation of appropriate policy measures at different levels, including but not limited to buildings, transport, and energy generation. During the past few years, important policy direction has been taken by several ministries in Malta and a number of key policy documents on climate change and energy efficiency have been published for public consultation.

The literature review has also covered several studies dealing with energy analysis in different buildings including offices, which is the focus of this dissertation. One of the approaches identified is an energy audit. This is a useful tool for creating and implementing comprehensive energy management plans. It takes an optimal approach to energy efficiency and strives for continuous development. In most studies for similar climates and same-purpose buildings it was revealed most of the energy consumed is due to HVAC and the energy-saving measure to take is maximizing daylight utilisation and natural ventilation. The above literature review showed that energy audits are effective and help to determine significant energy savings. However, they could be time consuming and expensive to carry out.

On the other hand, statistical and regression methodological approaches require highly skilled personnel and are computationally expensive, i.e., they require many hours of analysis and computation, which also makes them quite expensive to implement. Moreover, if the operation of the building is slightly changed, the whole exercise might need to be re-modelled to ensure the right and most optimum energy efficiency results.

Conversely, using modelling software has many advantages over the previous energy analysis methods, such as flexibility, speedy analysis, suitability to all different stages of the project (predesign, during construction, during renovation), as well as the ability to carry out pre-feasibility analysis of different energy efficiency measures before being implemented to take the appropriate and most effective decisions.

This project will therefore focus on modelling of the office under consideration to evaluate different energy efficiency measures that have not been considered before. The previous study carried out for the same office block was based on an energy audit of appliances and the potential of solar photovoltaics on the roof but not on the building envelope and the building energy systems [88]

Additionally, a walk-through audit will be carried out to review the situation in the offices as well as carry out additional testing that was not covered in the previous study, specifically on lighting levels in the offices and the carbon dioxide and other air pollutants concentration, given the Covid-19 pandemic situation that now requires more careful consideration of fresh air in confined spaces. The next chapter on Methodology explains the approach in more detail.

3 Methodology

This chapter will detail all the procedures that have been carried out to perform the energy analysis of the indicated office building. The methodology proposed to proceed with the energy audit, can be summarized as follows [56]:

- Acquire knowledge of the company's operations, i.e., how much energy it consumes, where and how.
- Carry out a walk-through observation exercise and also check carbon dioxide emissions as well as other air pollutants levels in different areas.
- Identify potential areas and potential energy efficiency measures that can be applied.
- Model the building and its energy services in DesignBuilder-EnergyPlus software.
- Compare actual energy consumption to modelled energy for calibration purposes
- Model the potential energy efficiency measures and evaluate their effectiveness in DesignBuilder-EnergyPlus.
- Compare the reference energy rating to the improved performance.
- Prioritise energy efficiency measures from an energy impact point of view.

In Figure 8, the Energy Audit process is represented in the form of a flow chart.

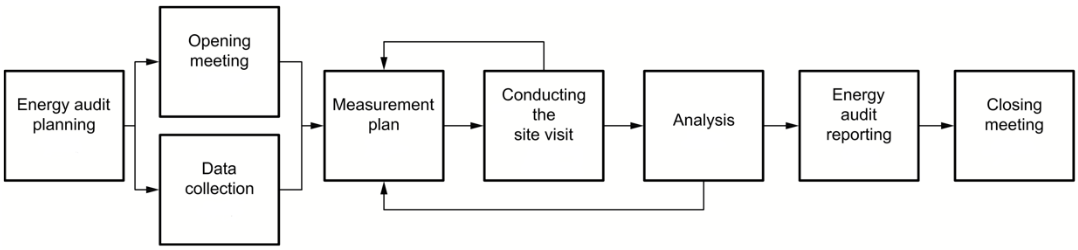

Figure 8. Energy Audit flow chart (ISO5002:2014)

3.1 Preliminary Information

This is the starting point for the energy audit. It takes place before the visits to the office to ensure that the team has the necessary information for a good preparation and organisation of the work. All background information such as environmental, geographic, or climatic was reviewed and all available information on the facilities was gathered to be able to plan the work properly.

Co-operation with the audited management was to be also co-ordinated by explaining what the audit will consist of and requesting the following preliminary information:

- General contact details of the office.
- Nature of work in the office, schedules, work calendar.
- Architectural drawings
  - Floor plans and elevations…
  - Heating and cooling installations plan (if available)
  - Hot water supply plans (if available)
  - Electricity bills
- Any available inventory such as for luminaires and lighting fixtures, installed equipment

In many cases it is advisable to complete this information with an earlier visit, which not only achieves this but also improves coordination with the office staff and provides first-hand information on the actual operation of the office. Quite often when one carries out such a review it is possible to discover equipment that is not in proper condition.
With this information, it is possible to proceed with the planning of the work to maximise the use of the time spent on the energy survey and the subsequent modelling of the building by software

For the purpose of simulation, the appropriate weather file has been supplied by the Institute for Sustainable Energy, for the year corresponding to the electricity bills provided by the company for its energy consumption. This will help in the comparison between actual energy consumption and simulated data to achieve appropriate calibration.

3.1.1 Building configuration

The volumetric shape of the project is based on a nearly horizontal volume made up mostly of two sub-buildings, one with access from the north-west via Old Bakery Street, and the other with access from the south-east via Strait Street. In Figure 9 the existing elevation of the building from Old Bakery Street can be seen.

Figure 9. Building elevation from Old Bakery Street

Figure 10 details the view of the façade from Strait Street.

Figure 10. Building elevation from Strait Street

To make an accurate simulation of the building, it is of vital importance to designate which materials the different building components are made of, as these have a direct influence on energy losses. This is considered as part of the methodology to carry out a survey of all materials comprising the different components of the building envelope and then calculate the U-value for each component to be inputed into the simulation model.

For a correct energy simulation, floor plans, including the roof, are also necessary, as these will be used as a basis for modelling the different partitions and perimeters of the building. The building is elevated on 6 floors, each of them containing offices, meeting rooms and several different areas, such as a kitchen, circulation areas, toilets, and storerooms.

3.2 Data Collection

Data collection is carried out through the compilation of information, both from documentation provided by the office staff, as well as information obtained through visits to the facilities.

Information provided by the company, together with the measurements taken on site constitute the fundamental basis of the audit.

The information to be collected was as follows:

3.2.1 Electricity bills

Historical data of energy consumption in the building provides a picture of the building's situation and acts as a reference for the software simulation results, against which these bills will be compared. In this way it is possible to identify the accuracy of the simulation carried out and the definition of appropriate measures to minimize bills while maximizing energy efficiency. The data provided by the company was for the full year 2020 and part of the year 2021.

3.2.2 Building plans

Obtaining the building layout distribution is crucial in order to model the perimeter and every area of the facilities. To define the different thermal zones, it is also vital to know what activity takes place in each part of the building based on the plans. This was carried out during the site visits, as will be shown in Chapter 4 on Results.

3.2.3 Construction data

In order to make the modelling simulation as accurate as possible, it is necessary to enter various building data such as the materials of each layer of the walls, floor, and roof as well as data on lighting, DHW, HVAC, etc. into the simulation software DesignBuilder, software specialised in the environmental and energy simulation of buildings. Its advanced features allow the evaluation of aspects such as comfort levels, energy consumption and carbon emissions. Once again, observations were carried out for different floors and for different rooms during the visits.

3.3 Measurement

Two types of measurements are carried out during the site visit, dimensional measurements and measurements of different factors that contribute to the building comfort through different measurement devices.

3.3.1 Dimensional measurements

Thanks to the plans provided, most of the dimensional measurements necessary for the correct modelling of the building were obtained, but a very important feature the plans did not provide are the dimensions of the different apertures, which are essential in the simulation to determine the energy losses and gains that occur in each, as well as the internal heights from floor to ceiling.

During the site visit, the size (height and width) of each external opening on every floor was measured and manually located on the plans provided for its input into the simulation software.

3.3.2 Measurement devices

A wide range of instruments with specific uses were necessary to analyse different factors that determine building comfort.

These devices are used in different offices visited to subsequently analyse the results obtained and determine whether the conditions in the office are suitable for the workers. The equipment used is as follows.

3.3.2.1 Lux Meter

A lux meter is a measuring device to measure the quantity of light or brightness in an environment the human eye can perceive.

Operating the luxmeter is simple. The lux level is sensed by an external silicon photodiode that has a spectral filter and an integrated circuit that, upon receiving a certain amount of light, can transform it into electricity. Depending on the intensity of the electricity, the lux level is known [12]. Lux meters can have different scales depending on the quantity of light to be measured, to have a higher precision depending on the intensity of the light.

Operation

Firstly, the photoreceptor is placed at desk level. Once this step has been completed, the reading appears in lux.

Components

- A **photoreceptor**. Perceives the light intensity to be measured and transforms it into electrical energy, which is then transported to the reader. Part of a photoresistor.
- A **reader**. Receives the electrical signal sent by the photoreceptor and transforms it into a brightness measurement. This measurement is then displayed on the screen.

In Figure 11 a Lux meter like the one used for this analysis can be observed.

Figure 11. Lux meter [91]

Recommendations

Illuminance is a parameter very sensitive to any change in the orientation of the photoreceptor, the height at which it is placed, shadows, etc. and there are large divergences between the readings of different devices (the margin of error is therefore usually large). In addition, the sensitivity range of the human eye is very wide: from a few to tens of thousands of lux. Therefore, results should be recorded as intervals between maximum and minimum readings.

For offices the lux level on a desk should at least be 300 Lux, according to the European standard EN 12464-1 [106]. This document establishes illuminance level for occupants in interior work environments that suit the needs of people with normal or corrected to normal visual capability in terms of visual comfort and performance [95].

3.3.2.2 CO_2 Meter

The Instrument that measures the concentration of carbon dioxide (CO_2) in a certain area gives an indirect but strong indication of the sufficiency of fresh air in the area. The CO_2 concentration is recorded in ppm (parts per million). Although CO_2 is not toxic, but if present in heavy doses for long periods, could make breathing difficult, cause headaches and drowsiness.

Due to the SARS-COV-2 virus, the adequacy of fresh air in closed environments is very important to reduce the risk of contracting COVID-19. Therefore, part of the survey in the office block included the check of CO_2 levels in all the offices.
In Figure 12 the model of CO_2 Meter used with its components indicated is shown.

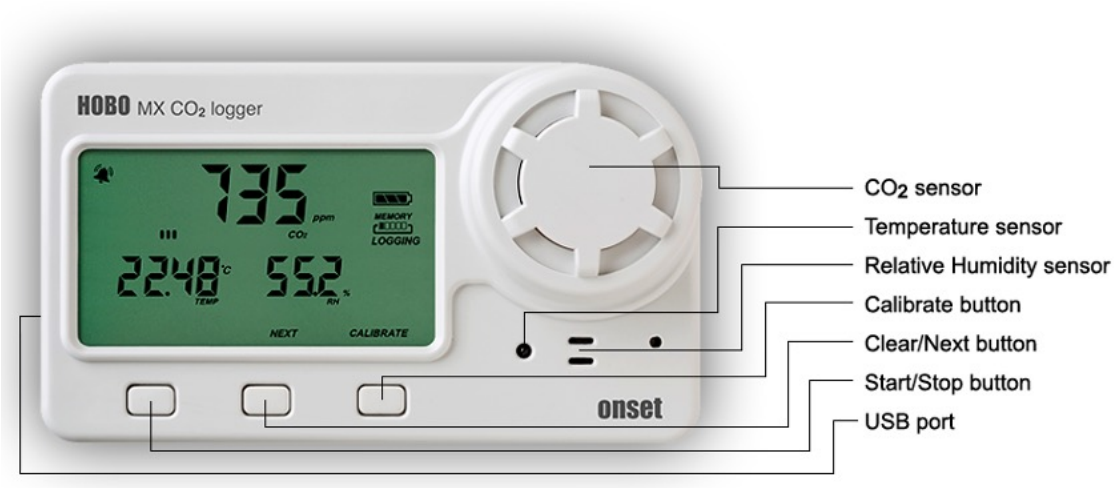

Figure 12. CO_2 Meter [92]

Placement

The amount of CO_2 in an enclosed environment varies. Monitors should be kept away from windows, doors, and apertures for air supply. Due to CO_2 present on breath from occupants, , monitors should be placed at least 50cm away from persons. If the monitor is too close to the subject, it may produce a falsely high reading. It is advised to try out a few different places to determine the most accurate result for the monitor in the room. More than one testing location is frequently necessary in bigger areas [93].

Reading

An indoor room with a continuous CO_2 concentration below 800ppm is considered to be sufficiently ventilated, while CO_2 levels in an occupied room that are continuously higher than 1500ppm suggest insufficient ventilation and should be addressed [93].

Table 2 below displays the impact of different levels of CO_2 on human beings [57], [58], [59].

Table 2. Levels of CO2 and their impact on human health [57, 58, 59]

CO_2 Level (ppm)	CO_2 Impact
250-400	Normal levels of CO_2 on air outdoors
400-1000	Busy indoor areas with admissible air flow.
1000-2000	This CO_2 level is linked to somnolence and low oxygen levels.
2000-5000	Congested air deriving in somnolence, depletion of consciousness. Some individuals may suffer minor nausea and higher heart rate.
5000	5000ppm is the 8-hour accumulative normal bound
>40,000	Hazardous to life or health.

Effectiveness

CO_2 monitors will only be useful in specific work environments. They are not suited for usage in regions where air purifiers are used since these remove pollutants from the air (such as coronavirus) but not CO_2.

Its application is limited in areas with few people, such as fitting rooms or large offices with a low number of occupants or in large, open areas with high ceilings, like manufacturing halls or storage facilities, where air may not be completely mixed therefore CO_2 monitors could be less accurate [93].

3.3.2.3 Particle counter

A particle counter is an instrument designed to detect and count particles to determine the level of air pollution. Pollution is mainly generated by combustion, material processing, manufacturing, energy production, vehicle emissions, dust, and volatile organic compounds.

Particles can be of different sizes and shapes, such as skin flakes, hairs, spores, pollen or grains of soil or pieces of metal. Generally, instruments measure light scattering and report the particle size as if the scattering was created by a fully spherical particle, so the measurement does not correspond exactly to the dimensions of the particle, but to the dimensions of the spherical particle that would diffract the same amount of light [60], [61].

In Table 3 a description of allowable particle concentrations for ISO standard is detailed [79].

PM10: Particles with a diameter of 2.5 to 10 µm (from about 25 to 100 times thinner than a human hair). These particles mostly affect the upper respiratory system and create less severe health consequences. Smoke, dirt, and dust from industries, farms, and traffic, as well as mould, spores, and pollen, are all examples.

PM2.5: Refers to tiny particles with a diameter of less than 2.5 µm (more than x100 thinner than a human hair). Toxic chemical molecules and heavy metals are among them. They are created from automotive emissions, rubbish and landfill burning, as well as metal smelting and processing. Both concentrations are quantified in micrograms per cubic meter. The tiny particles, known as PM2.5, can penetrate deep into the lungs, causing more long-term harm than PM10. They also move further and remain for a longer time in the air. PM10 (large) particles can last minutes or hours in the air, while PM2.5 particles last days or weeks. PM10 particles may travel up to 30 kilometres, in contrast with PM2.5 particles which can move hundreds of kilometres or more.

Table 3. ISO 14644-1:2015 Classes of air cleanliness by particle concentration [79]

ISO Class number (*N*)	Maximum allowable concentrations (particles/m³) for particles equal to and greater than the considered sizes, shown below[a]					
	0,1 µm	0,2 µm	0,3 µm	0,5 µm	1 µm	5 µm
1	*10*[b]	d	d	d	d	e
2	100	*24*[b]	*10*[b]	d	d	e
3	1 000	237	102	*35*[b]	d	e
4	10 000	2 370	1 020	352	*83*[b]	e
5	100 000	23 700	10 200	3 520	832	d, e, f
6	1 000 000	237 000	102 000	35 200	8 320	293
7	c	c	c	352 000	83 200	2 930
8	c	c	c	3 520 000	832 000	29 300
9[g]	c	c	c	35 200 000	8 320 000	293 000

[a] All concentrations in the table are cumulative, e.g. for ISO Class 5, the 10 200 particles shown at 0,3 µm include all particles equal to and greater than this size.

[b] These concentrations will lead to large air sample volumes for classification. Sequential sampling procedure may be applied; see Annex D.

[c] Concentration limits are not applicable in this region of the table due to very high particle concentration.

[d] Sampling and statistical limitations for particles in low concentrations make classification inappropriate.

[e] Sample collection limitations for both particles in low concentrations and sizes greater than 1 µm make classification at this particle size inappropriate, due to potential particle losses in the sampling system.

[f] In order to specify this particle size in association with ISO Class 5, the macroparticle descriptor M may be adapted and used in conjunction with at least one other particle size. (See C.7.)

[g] This class is only applicable for the in-operation state.

The European Air Quality Index

Table 4 shows the European AQI (Air Quality Index) categories and levels for various pollutant concentrations.

Table 4. EU AQI for Particles [75]

Index level (based on pollutant concentrations in µg/m3)	Pollutant	
	Particles less than 2.5 µm (PM2.5)	Particles less than 10 µm (PM10)
Good	0-10	0-20
Fair	10-20	20-40
Moderate	20-25	40-50
Poor	25-50	50-100
Very Poor	50-75	100-150
Extremely poor	75-800	150-1200

In Table 5 the impact on human health generated by particulate matter depending on the Air Quality Index is shown.

Table 5. Health impact of AQI designations

Index level	Health impact
Good	Insignificant
Fair	Minimal breathing difficulties to sensitive people
Moderate	Asthmatic patients, the elderly, and children have difficulty breathing.
Poor	General discomfort when breathing
Very poor	Long-term exposure causes respiratory disease.
Extremely poor	Heart and lung disease sufferers severely impacted.

Total volatile organic compounds (TVOC)

Organic compounds are carbon-containing chemicals found in all living things. Volatile organic compounds, sometimes called VOCs, are easily converted into vapours or gases that contribute to poor indoor air quality and could be abundant both indoors and outdoors.

VOCs are organic chemicals emitted as gases by-products or processes; generally, they can be smelled. Typical indoor sources of VOCs include things like cleaning agents, disinfectants, air fresheners, dehumidifiers and more [75]. This is especially compounded by the fact that sanitisers are being used all over the world and inside offices, which will cause high concentration of TVOC that the employees are exposed to for prolonged periods of time.

In Table 6 the degrees of concern posed by the presence of VOCs depending on their concentration levels is depicted.

Table 6. Level of concern for TVOC concentration levels [76]

TVOC Level mg/m³	Level of Concern
Less than 0.3 mg/m³	Low
0.3 to 0.5 mg/m³	Acceptable
0.5 to 1 mg/m³	Marginal
1 to 3 mg/m³	High

Formaldehyde (HCHO)

Formaldehyde or methanal is a chemical compound, more specifically a highly volatile and highly flammable aldehyde, which is obtained by catalytic oxidation of methyl alcohol.

It is a widespread allergen as it is present in multiple products and is incorporated into many others in manufacturing processes including plastics, cutting fluids, medicines, fabrics, cosmetics, and detergents.

This chemical is widely used as a bactericide or preservative, in the manufacture of clothing, plastics, paper, boards and many other uses. Formaldehyde is in fact widespread in our environment. It can also be found in many products as a decomposition or alteration product [75].

To know which amount of HCHO could produce harm to occupants, levels of concern are assigned to different concentration levels as shown in Table 7.

Table 7. Level of concern for HCHO concentration levels [77]

HCHO Level mg/m³	Level of Concern
Less than 0.05 mg/m³	Low
0.05 to 0.123 mg/m³	Moderate
Above 0.123 mg/m³	High

Once again, the regular use of hydroalcoholic gel for sanitising hands against the CORONA-19 virus can significantly increase the levels of these compounds in indoor spaces, so it is important to check that they are within healthy levels.

Figure 13 shows the instrument that was used during the site visits to check the above pollutants.

Figure 13. Particle counter [94]

3.4 Building Energy Modelling

After the audit was completed and all the data compiled, the next step was to model the building using a simulation software. For this study, the renowned software

DesignBuilder, version 7.0.0.116 (2021) was used. In order to prepare the model in DesignBuilder, it is necessary to follow a series of steps. A chronological overview of the process would be [62]:

3.4.1 Importing CAD files

Plans collected from each of the building levels must be imported before the building modelling can start. In this way the plan for each floor can be taken as a reference to begin drawing the envelope and the different partitions. In Figure 14 an example of the overview of the building model based on one of the floor plans is displayed.

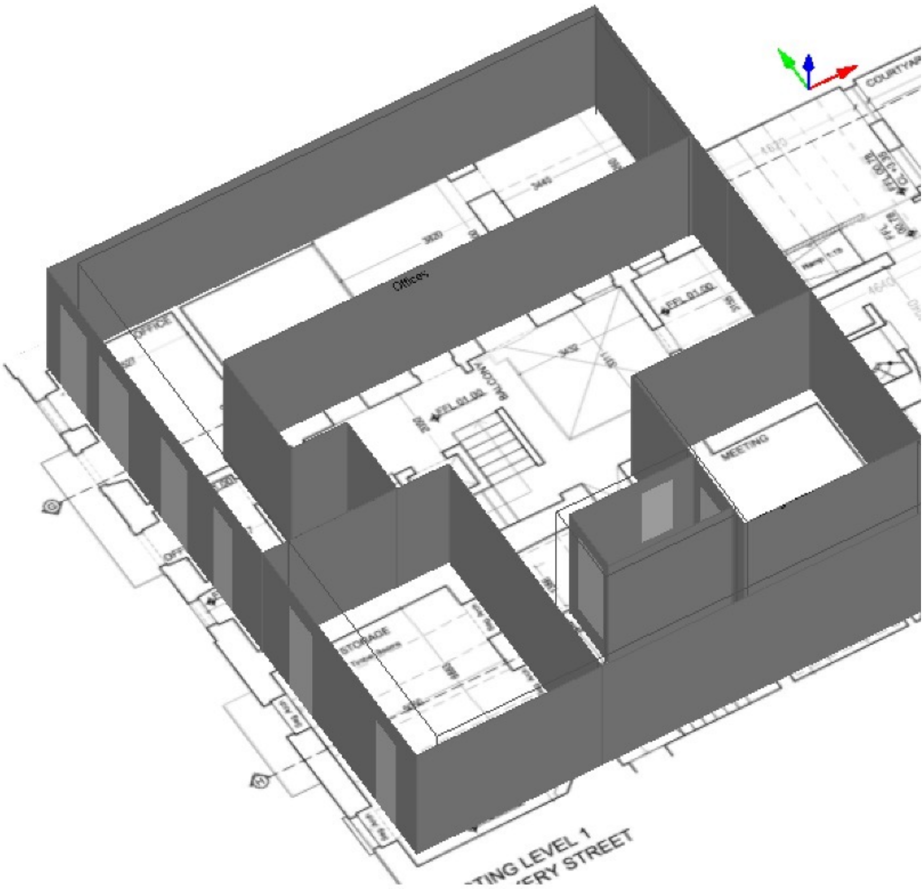

Figure 14. Building model from plan example

3.4.2 Design and layout of each floor importing CAD files

After rescaling the plans by taking a reference dimension, the perimeter of the building is drawn forming the external walls. Internal partitions are then made separating zones by activity i.e., offices, meeting rooms, kitchen, circulation area. Internal partitions subdividing offices can in general be ignored because they have low thermal mass and do not affect the accuracy of the results. This also accelerates the process of building up the model and running it in DesignBuilder. In the building case study, there is also the need to create holes due to the existence of internal yards or shafts.

In Figure 15 the layout of a part of one of the floors is shown.

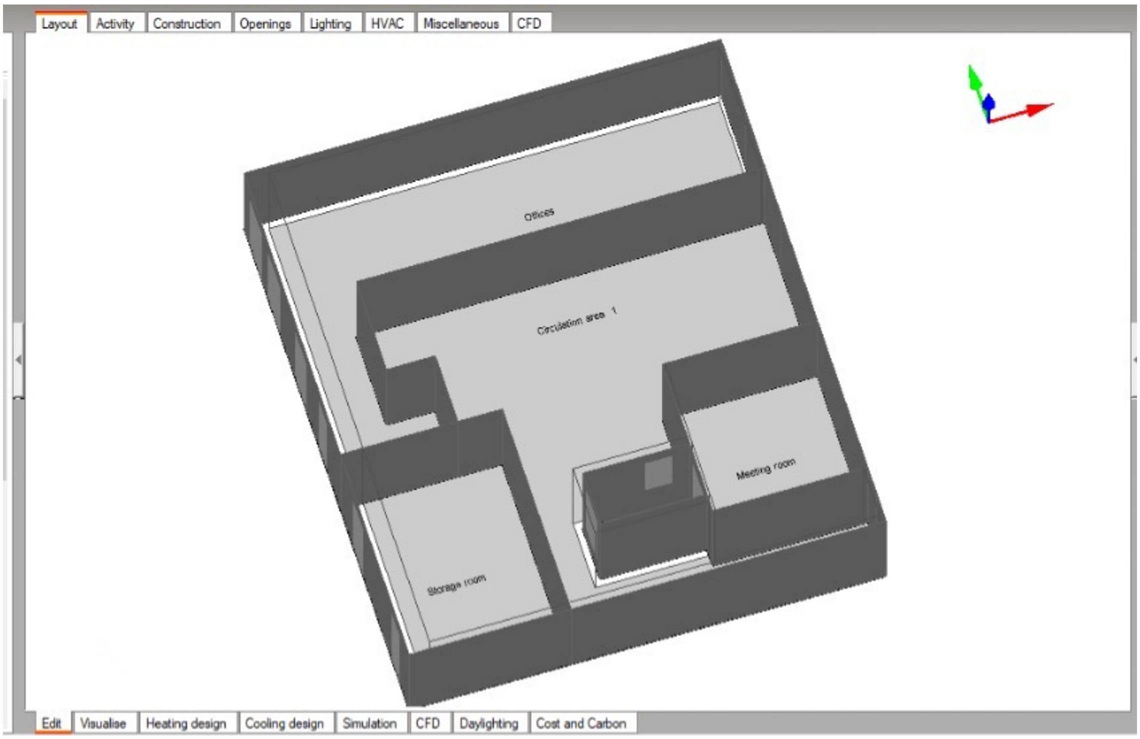

Figure 15. Internal partitions modelling example

3.4.3 Activity settings

This section defines those aspects that refer to the activity that takes place in the building such as:

- Occupancy, is established by the number of people per unit of floor area, where occupancy times are controlled by programming. Standard values of occupancy for different zones are provided by the software and these are based on international standards. In the exceptional case that some offices have less occupancy, the user can adjust the figures for those offices.

- Environmental control is set by temperature setpoints for heating and cooling, configured at building level. In general, the same setting is assumed for all the zones having the same use such as offices. However, for specific demand, the user can also tweak the input parameters to reflect reality in a better way. Nevertheless, one has to be careful to keep a balance between what is expected to be considered as comfortable in terms of temperature settings and what certain users prefer to do. The primary concern here is that the modelling should as far as possibly follow the rule rather than the exception.

After each zone is labelled, characteristics for the activity of every area are defined, in this case every thermal zone is initially defined as an office.

In Figure 16 an example of activity template assigned to the kitchen as a food preparation area is shown.

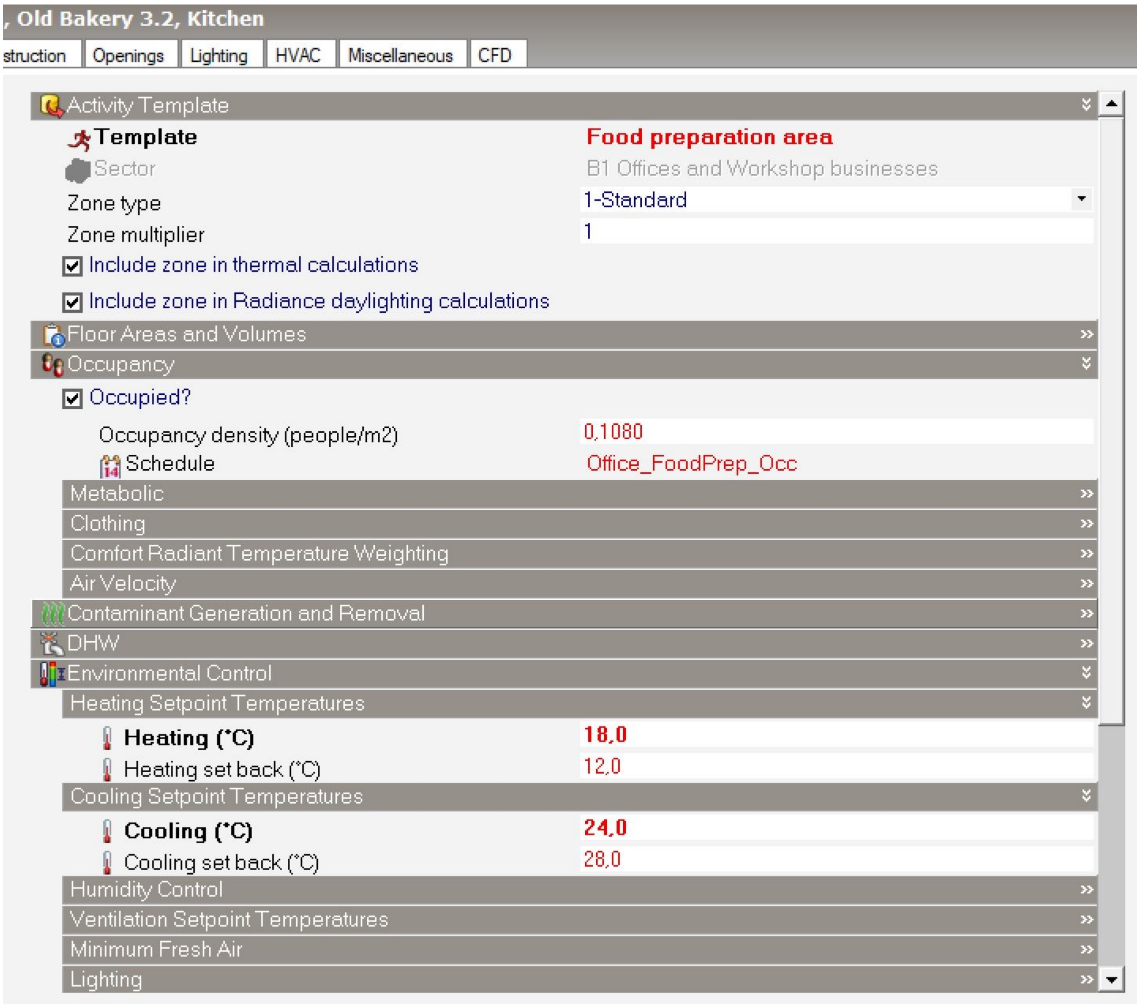

Figure 16. Example of activity settings

3.4.4 Defining envelope characteristics

Before defining construction settings, it is necessary to set the climatic background in which the building stands, in this case, Valletta, Malta. The weather file for 2020 has been provided by the Institute for Sustainable Energy of the University of Malta.

The building's thermal envelope is the skin that protects the building from the temperature, air, and humidity from the outside, to improve the quality of life of its occupants.

With the information collected in the construction section, Design Builder creates each of these materials with the values of thickness, thermal resistance, and the value of resistance to water vapour that make up the roofs, walls, and different floors, to end up making up all the types of construction systems.

In Figure 17 the different layers and materials from which one type of external wall from the building is composed.

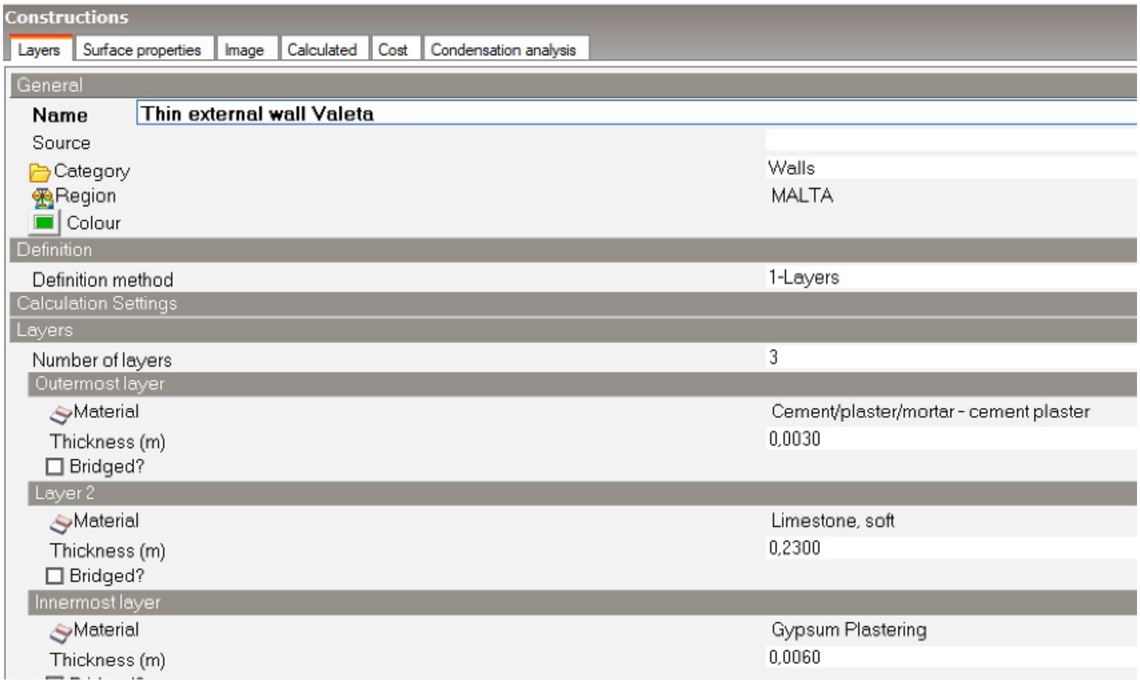

Figure 17. Example of construction layers setting

In Figure 18 different templates for building construction (roof, ground, walls…) can be observed. Airtightness, i.e., resistance the building withstands to air infiltration without ventilators ON [80], is also envisaged in the simulation, defining its constant rate.

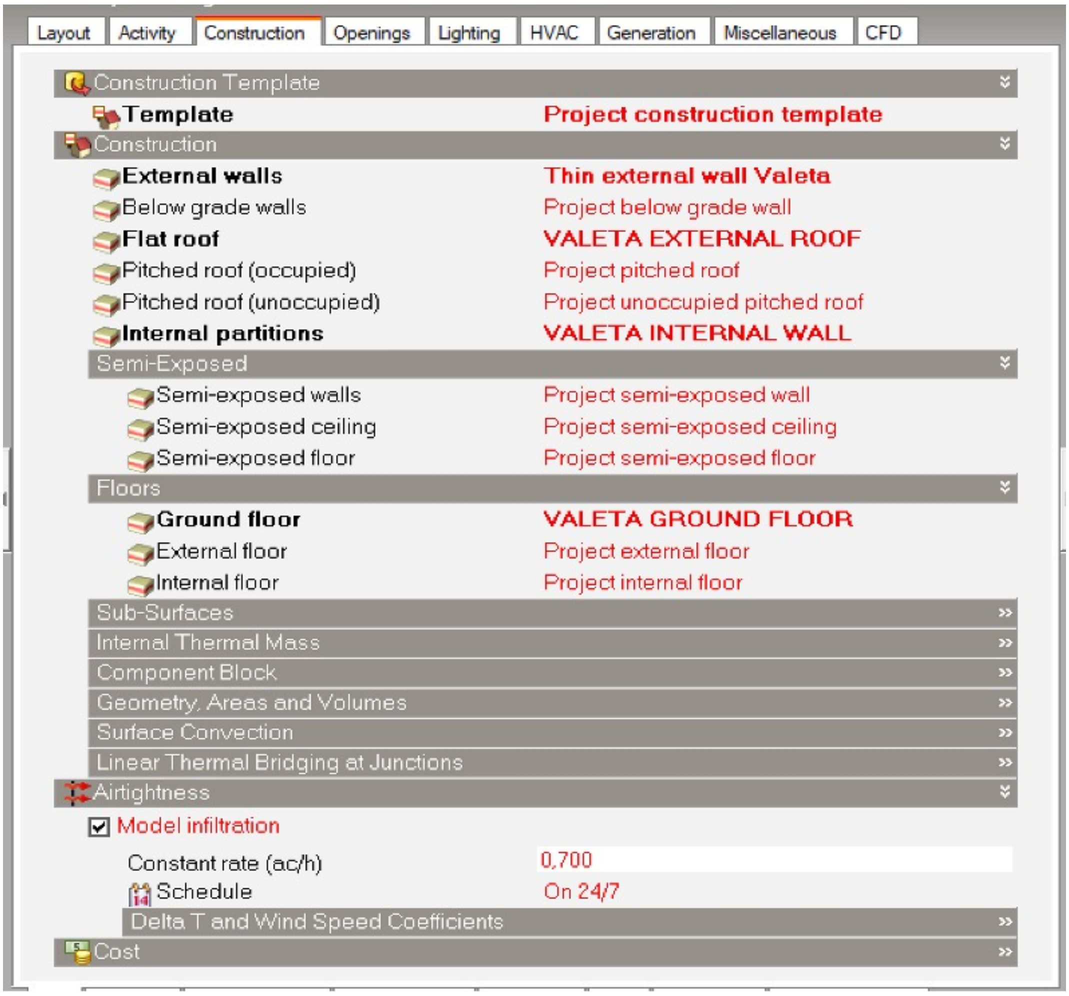

Figure 18. Construction Templates definition and Airtightness

3.4.5 Defining openings criteria

The different windows located on the facade of the building and external doors also need to be detailed as they are points where infiltrations are created. As measured in the site visit, windows are set by annotating their width and height and a distance from the floor of 1m by default. Glazed external doors are set as windows too, with the difference that they start from the ground. All openings are defined as double glazing as verified during the site visit.

Figure 19 shows an example of an opening characteristics definition.

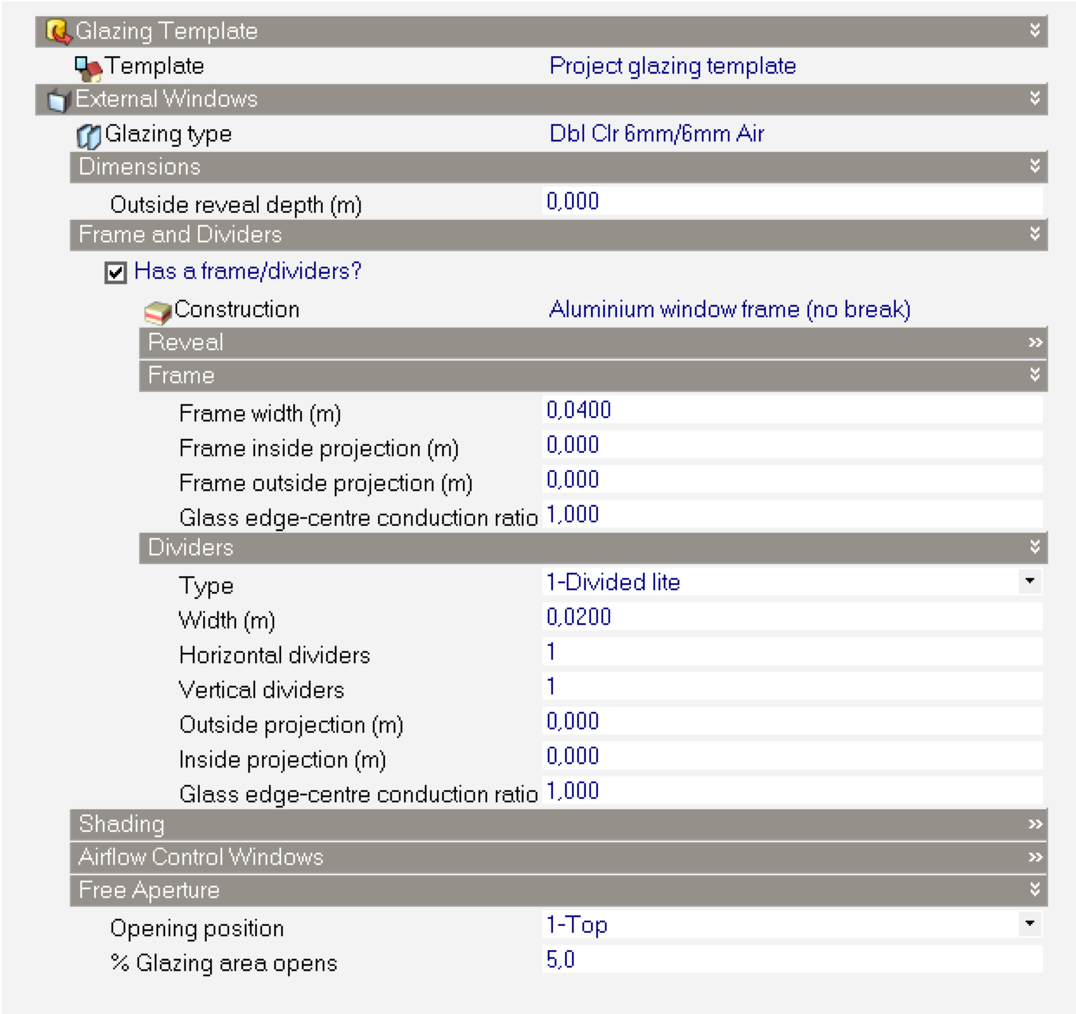

Figure 19. Window characteristics example

3.4.6 Illumination settings

Several lighting features can be determined in the simulation, for example type of luminaire present in the office.

To analyse different kinds of scenarios, some characteristics can be changed and compared, such as the existence of task and display lighting or lighting control. In this way, it can be determined whether the use of these features can be beneficial in the office in terms of maximizing comfort and saving energy. In Figure 20, an example of general lighting characteristics definition is shown.

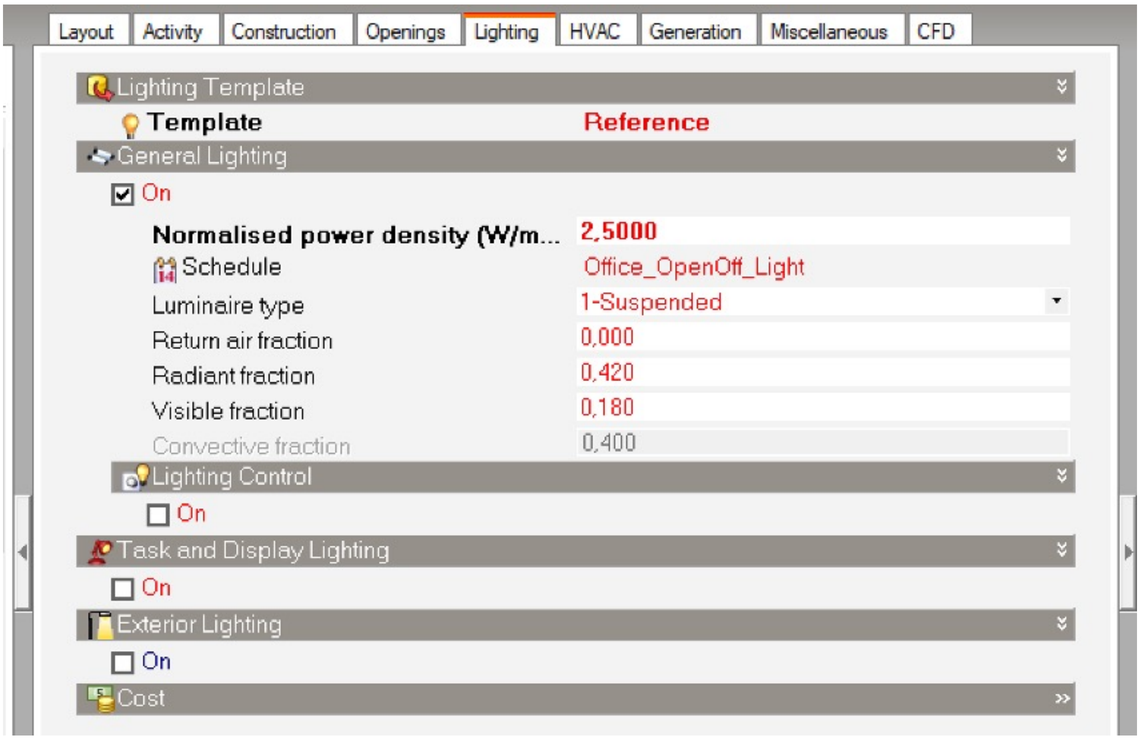

Figure 20. Lighting characteristics example

3.4.7 HVAC settings

The HVAC system assigned to the model is named Split unit, which consists of a system where external and internal units are interconnected by copper tubing [81]. This is the standard equipment used in many small and medium sized offices.

Fuel for both heating and cooling is obtained from the electricity grid and domestic hot water consists of a stand-alone water heater with electric resistance.

Natural ventilation of this building is not considered in the simulation, as the windows are opened and closed according to the demand of the employees, and not at a specific time.

An example setting for HVAC inputs are observed in Figure 21.

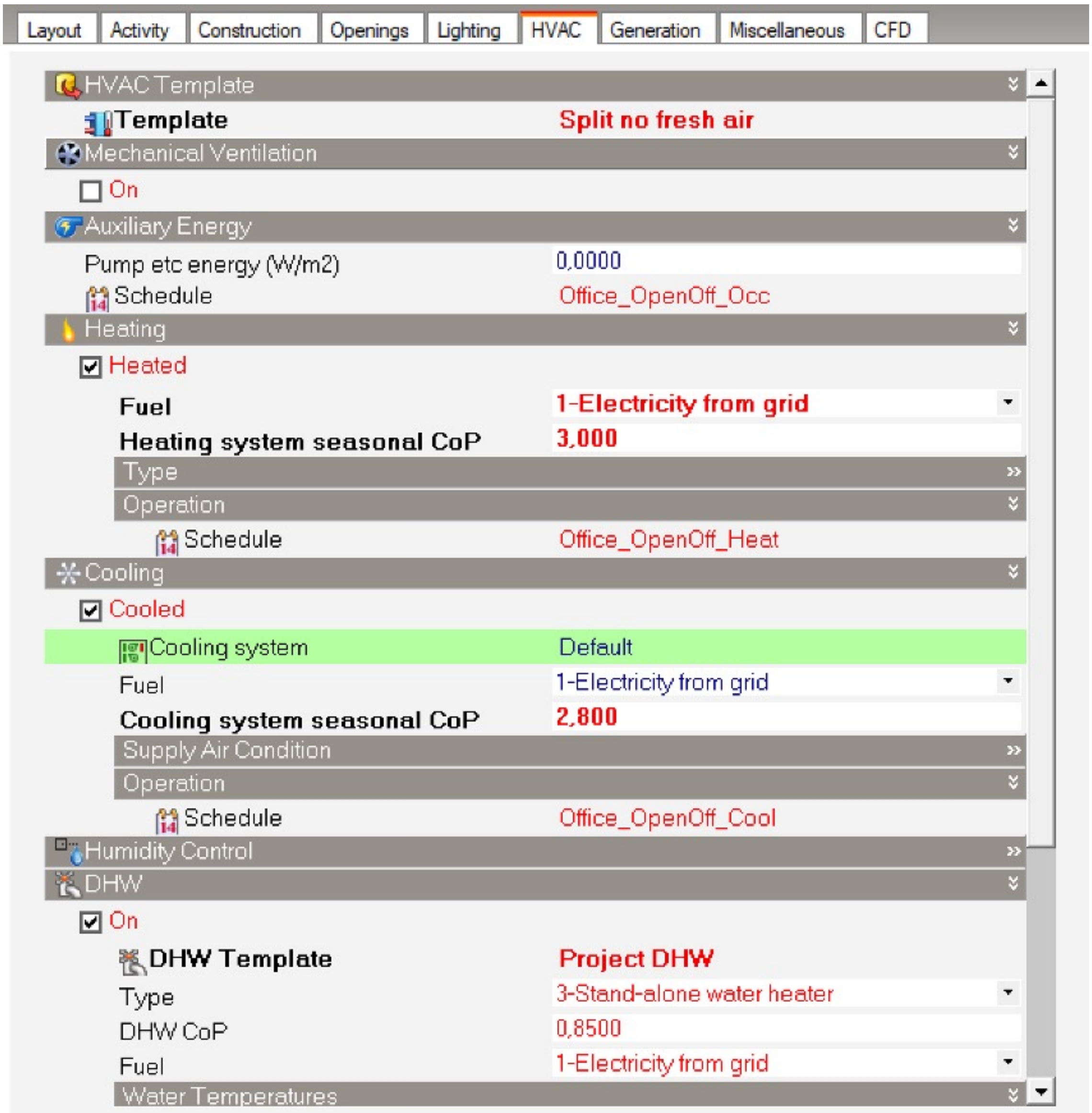

Figure 21. HVAC characteristics on simulation

Once the building has been properly modelled and all the necessary parameters have been defined, the simulation is carried out, from which the results to be analysed will be obtained.

3.4.8 Surroundings

In order to analyse the effect produced by the buildings adjacent to the one under study, it is necessary to introduce a new element, adiabatic component blocks. Adiabatic surfaces are utilized to model borders with other areas since they do not transmit heat beyond their outer surface [101].

In Figure 22 a representation of the adiabatic component blocks in the simulation is displayed.

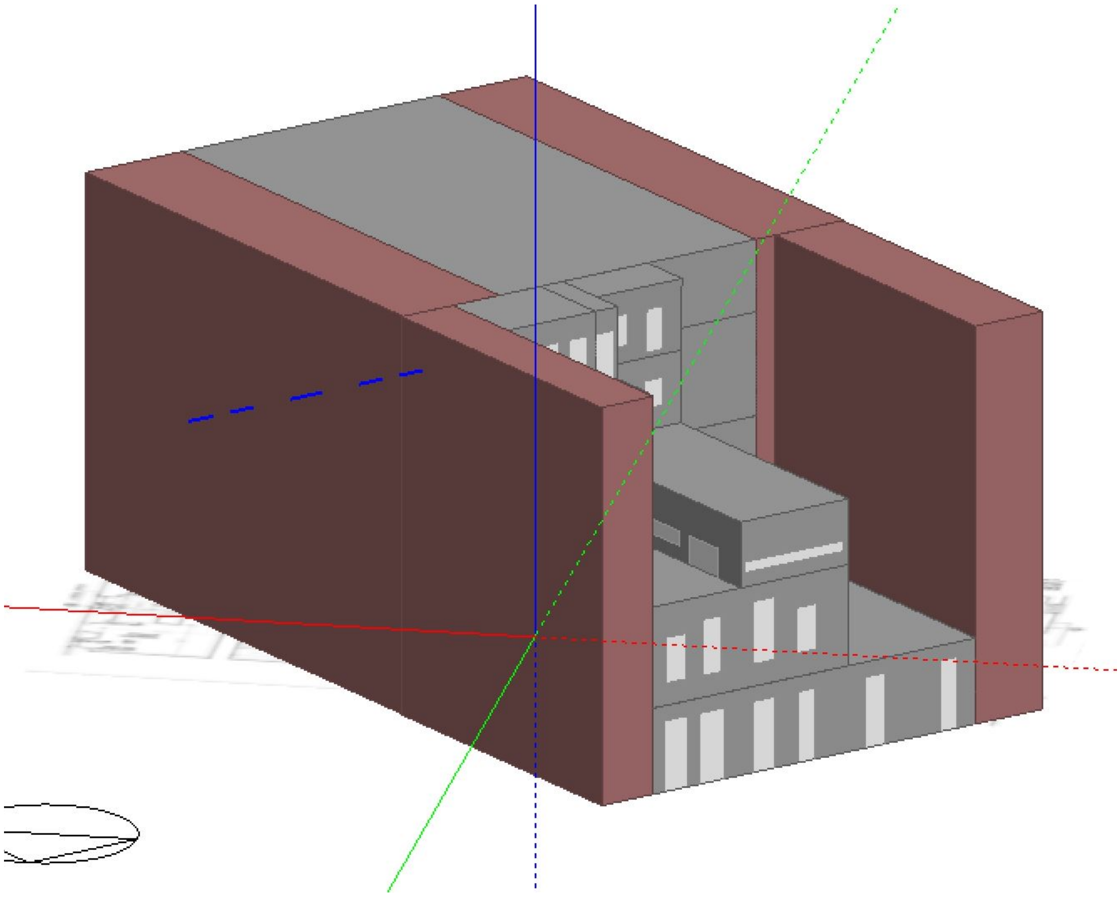

Figure 22. Adiabatic Component Blocks

3.5 Comparison to Actual Consumption

As indicated at the beginning of this chapter, the electricity bills for the building during 2020 and part of 2021 have been provided by the company under study. Through these provided bills, the accuracy of the simulation and the need for different energy saving measures are analysed by comparing the results obtained in the simulation and the actual consumption for the year 2020.

3.6 Energy Efficiency Measures

In order to analyse possible energy improvements in the building, different energy saving measures that could be implemented are evaluated. Once these measures have been identified, they are simulated in the building using DesignBuilder to compare their effectiveness and whether or not they should be implemented.

The proposed measures are grouped into three: measures applied to the building envelope, measures applied to the energy systems and renewables. These measures are detailed in Table 8.

Table 8. Energy saving measures

Measure		Description
Envelope	**Thermal insulation**	Insulating the roof and/or walls of the building prevents heat transmission through them, avoiding losses that generate a higher HVAC demand, i.e., higher energy costs. Insulation materials impede the flow of energy (heat) between two surfaces that are at different temperatures. Thermal conductivity is proportional to its insulating ability. That is, the rate at which a specific amount of energy is transported through the thickness of a material [97].
	Solar shading	Used as a kind of solar control, to maximize the quantity of solar heat uptake and visible light let into the structure. It has a considerable impact on energy consumption as well as occupant thermal and visual comfort, preventing overheating and glare on hot or bright days. Fixed or movable solar shade is available [96].
	Low emissivity windows	Low-E windows consist of glass coated with metallic oxide layers that are not visible. This coating is applied to reduce the quantity of UV and infrared light transmitted through glass while still allowing visible light to pass through. Low emissivity windows keep temperature constant by reflecting the internal temperature back inside [98].
Energy systems	**Desk lamps**	Analysing the effect of installing task lighting provides an insight into the need to improve lighting in offices and the effects that their installation has on the energy consumption and lighting comfort in the building.
	Lighting control	Automatic lighting control systems save energy by reducing lamp working times depending on parameters such as occupancy, time of day, and daylight availability. The technology and complexity of lighting control methods varies greatly. Automated controls may be used to turn on or off the lights at a basic level, moreover, these devices can sometimes also regulate lighting intensity based on the requirements [99].

3.7 Summary

The process of an energy audit follows a methodology with very distinct steps. Initially, some information about the building under study is required to establish a basis for the analysis. This description is about the location of the building as well as climatic and geographical details. It also includes information about the configuration of the building, detailing for example the different accesses to the facilities from the outside.

The next step in the procedure would be the data collection prior to the site visit. This collection consists of requesting the management to provide electricity bills for later comparison with the results of the simulation, plans of the building necessary for the modelling and construction data such as materials of which the building is composed, types of openings, etc.

Measurements are taken during the visit to the facilities, where two types of data are collected; dimensional data on the size of the different openings to the outside of the building façade and measurements using devices such as a Lux meter to determine different factors that contribute to the comfort of the offices, like lighting levels or air quality, the latter being currently of special relevance when it comes to preventing and analysing the effects produced by the Covid-19 measures.

DesignBuilder simulation is the tool used to obtain an estimate of the energy performance of the facilities in order to analyse the energy consumed by the building and the heat gains and losses that occur. In this way, energy saving measures can be identified at a later stage. The simulation process begins by importing the plans provided and using them to model the layout of the building in its different floors, then the activity for which each zone is intended and the construction characteristics that had also been provided are defined. It is also necessary to define the openings to the outside, the lighting and HVAC characteristics and the presence of adjacent buildings.

When the results of the simulation have been obtained, in order to assess whether it has been carried out correctly and how it can be improved, the energy results are compared with the actual energy consumption provided by the company at the beginning of the project.

Finally, different energy saving measures applicable to the building are identified in order to re-simulate the model again using each of them and determine whether they improve the energy performance of the building or not.

4 Results and Discussion

In this chapter, the results obtained in the audit are presented. On the one hand, the results of measurements using different devices to determine the level of comfort in the offices are shown, and on the other hand, the results obtained from the simulation of the office building using DesignBuilder are discussed.

4.1 Building simulation

The building was modelled in Design Builder and all appropriate input parameters were added to the model, such as material characteristics of walls, floors, roofs, and windows. Moreover, appropriate settings were made to the building energy systems such as lighting and air-conditioning. After completing the building modelling of the office, an extensive analysis of energy usage was carried out.

4.1.1 Building components

Table 9 shows a description of all the materials that make up each layer of the components, together with its corresponding U-Value (thermal transmittance) measured in W/(m².K) [78].

Table 9. Building construction parameters

Assembly	Material	Thickness (m)	U-Value (W/m^2. K))
Ground floor	Glazed Ceramic Tiles	0.0120	1.693
	Floor Screed	0.0800	
	Cast Concrete	0.2000	
Thick external wall	Limestone, soft	0.3500	0.999
	Air gap	0.0250	
	Limestone, soft	0.3500	
	Gypsum Plastering	0.0060	
Thin external wall	Cement plaster	0.0030	2.511
	Limestone, soft	0.2300	
	Gypsum Plastering	0.0060	
Internal wall	Plaster (Lightweight)	0.0060	1.838
	Limestone, soft	0.2300	
	Plaster (Lightweight)	0.0060	
External roof	Bitumen, felt/sheet	0.0040	0.963
	Roof Screed	0.0800	
	Limestone, semi-hard	0.0800	
	Concrete, Reinforced (2% steel)	0.2000	
	Plaster (Dense)	0.0030	
	Air gap (downwards)	0.0250	
	XPS Extruded Polystyrene - CO_2 Blowing	0.0120	

4.1.2 Building layout modelling

The overall description of the building is shown below.

Level 0/-1

In this floor one can find the entrance from Bakery Street, a small reception and several meeting and storage rooms.

In Figure 23 Plan for level 0/-1 is detailed

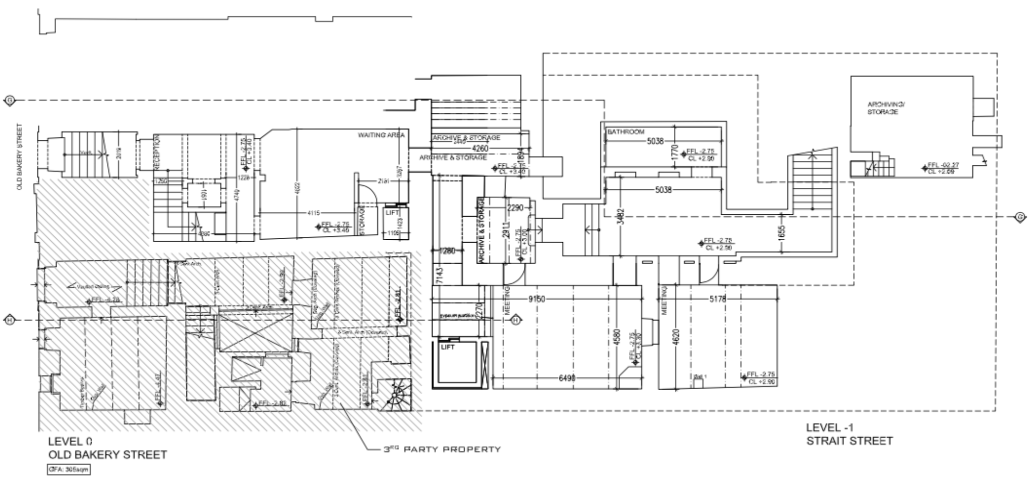

Figure 23. Level 0/-1 plan

Level 1/0-0A

On this floor the second entrance to the building is situated overlooking Strait Street. On this level, most of the rooms are composed of offices and meeting rooms.

To simplify the simulation process levels 0 and 0A were taken as a whole floor and this has no impact on the accuracy of the outputs, because the zones are still appropriately considered according to their use.

In Figure 24 Plan for level 1/0-0A is shown.

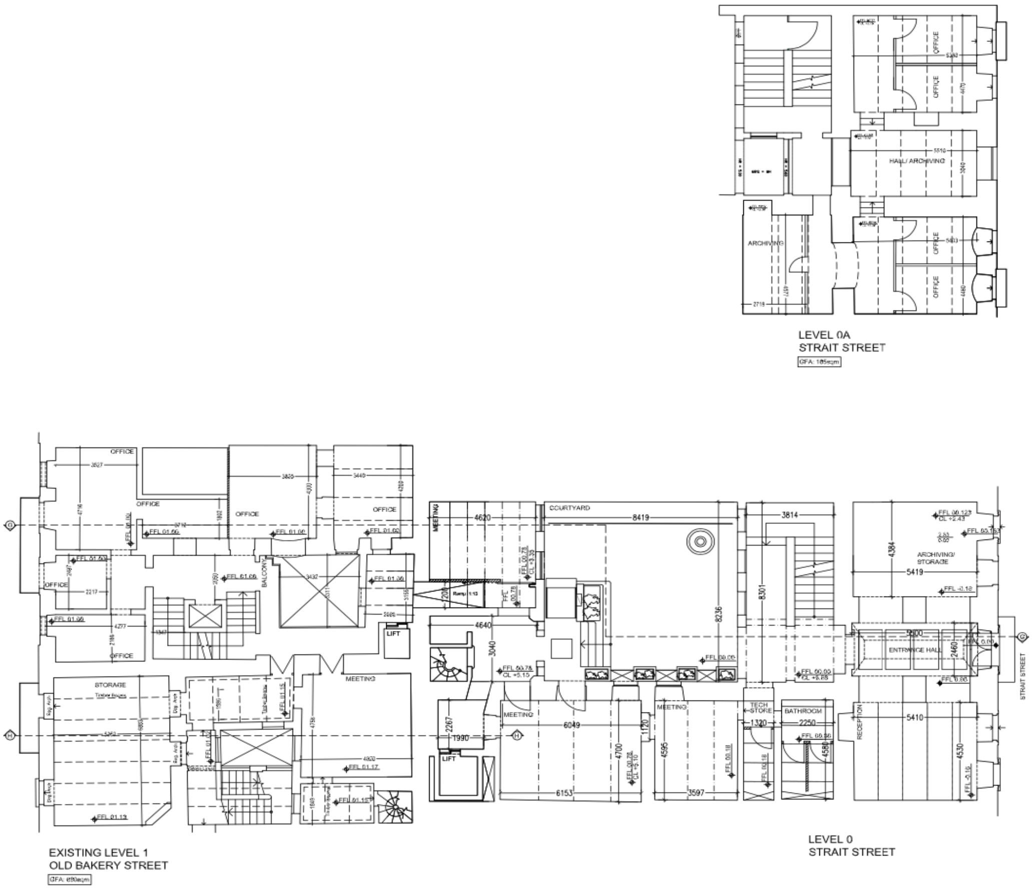

Figure 24. Level 1/0-0A plan

Level 2/1

This floor is entirely composed of offices, The existence of a sub-floor 2A was lumped with floor 2, similar to the one below it..

In Figure 25 Plan for Level 2/1 is shown.

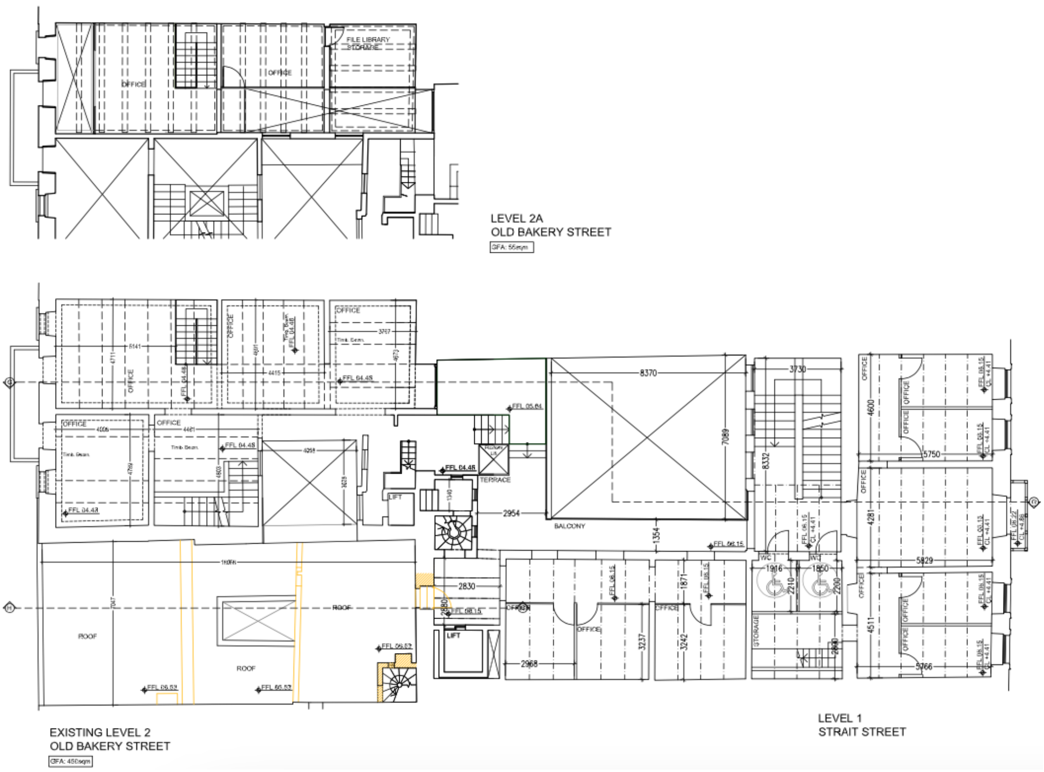

Figure 25. Level 2/1 plan

Level 3/2

In this floor, there is a mix of different use rooms such as a library, a kitchen, bathrooms, and offices.

Figure 26 shows the layout for this floor.

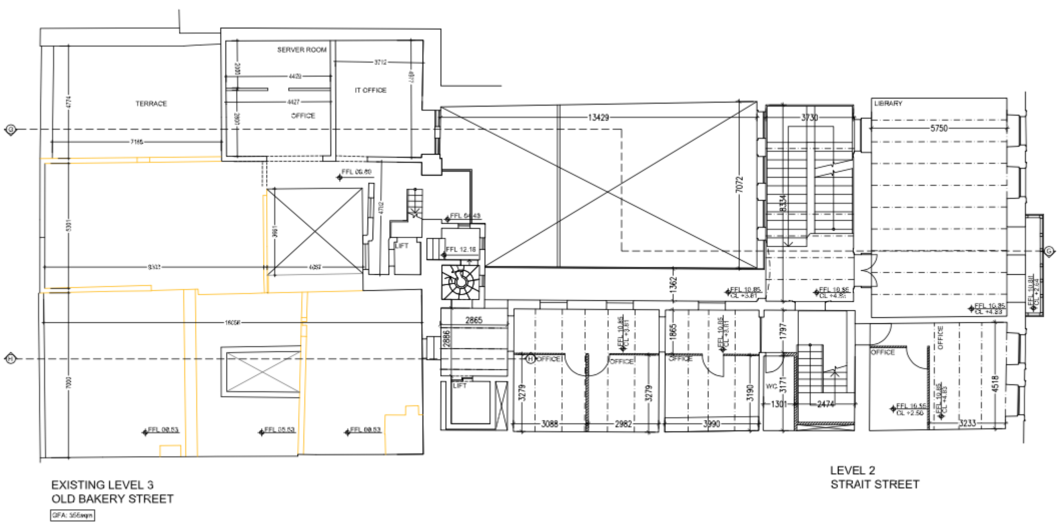

Figure 26. Level 3/2 plan

Level 4/2A

This floor contains a few offices and storage rooms.

Plans of this floor can be seen in Figure 27.

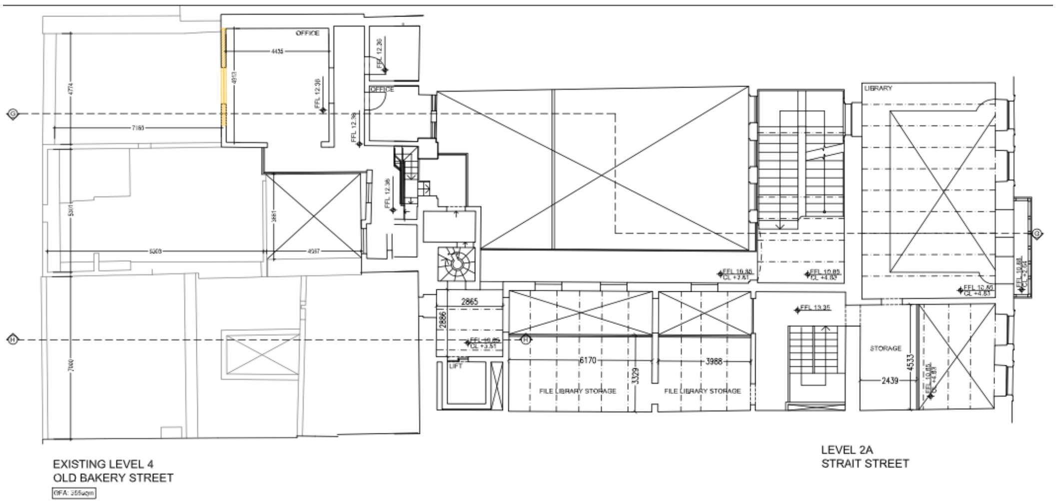

Figure 27. Level 4/2A plan

Level 5/3

In this floor, several offices are found together with a terrace where a glass roof can be appreciated. The glass roof covers the central courtyard, which is used as a waiting area. Plans of this floor is detailed in Figure 28.

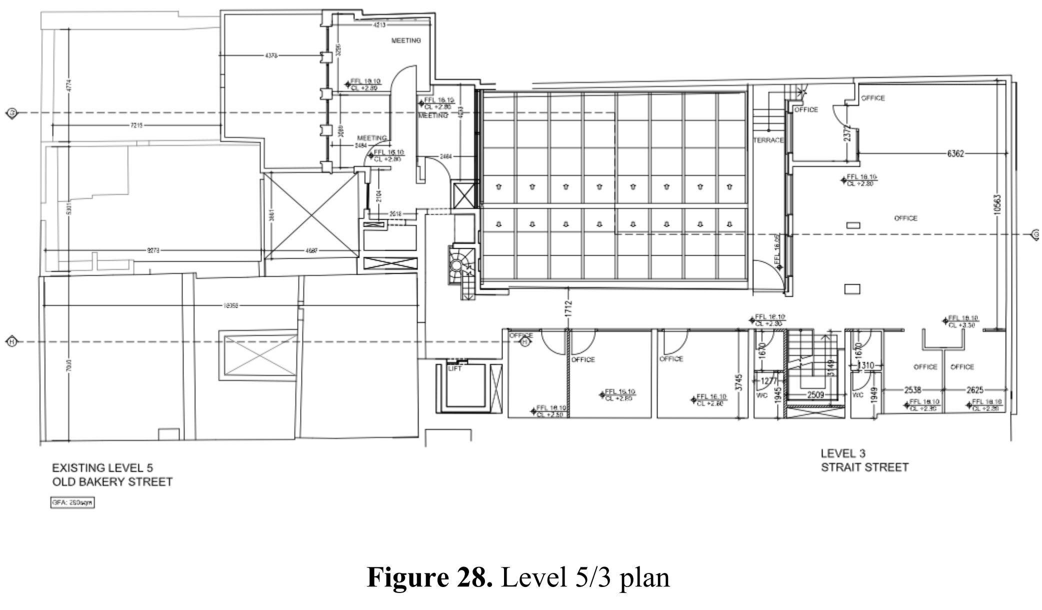

Figure 28. Level 5/3 plan

The roof plan is shown in Figure 29.

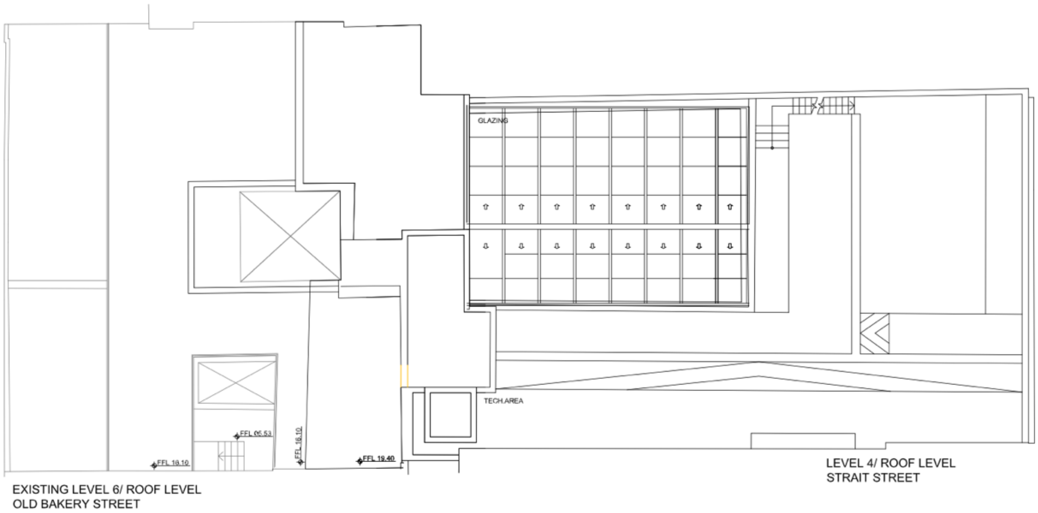

Figure 29. Roof plan

4.1.3 Building energy systems

4.1.3.1 Lighting

General lighting throughout the whole building is set as suspended luminaires with a Normalised power density of 2.5 W/m^2, which basically indicates the total load of all lighting equipment in a specific area.

For these specific parameters, a set of default values appropriate for the luminaire type is loaded as Table 10 shows [102].

Table 10. Luminaire parameters

Radiant Fraction	0.42
Visible Fraction	0.18
Convective Fraction	0.4

Radiant fraction means the portion of heat generated by lights that enters the area as long wave radiation. Depending on the area times thermal absorptance product of the surfaces, Design Builder determines the amount of this radiation that is absorbed by the inside surfaces of the room.

Visible fraction is the proportion of light-induced heat that enters the room as short-wave radiation. Depending on the area times solar absorptance product of the surfaces, the software determines the amount of this radiation that is absorbed by the inside surfaces of the room.

The fraction of heat from lights that is convected to the zone air is computed using the formula shown in Eq. (1).

$$Fr.convected = 1.0 - (Return\ Air\ Fraction + Fr.Radiant + Fr.Visible) \quad (1)$$

4.1.3.2 HVAC

The type of heating selected is fuelled by natural gas using a convective heating system which essentially means that the room is heated by an air system that is adjusted to the required temperatures [107].

DHW type set is Stand-alone water heater, it basically consists of a tank equipped with an aqua stat, which monitors the temperature of the stored water and controls the heat source as needed [108].

A relevant parameter for HVAC systems is the Coefficient of Performance (COP) which measures how efficient a heat pump or air conditioner is at transferring heat compared to the amount of electricity it consumes [103]. This information was collected based on the survey carried out for some accessible air-conditioners in the offices and inputted in Design Builder as Heating system CoP = 3, Cooling system CoP= 2.8 and DHW system CoP= 0.85.

It is also necessary to mention Heating and cooling operation schedule, to construct the time-varying heating setpoint schedule in the zone, this schedule data is combined with the heating and cooling setpoint temperatures on the Activity tab. The operation schedule specifies when full and setback setpoints should be fulfilled, whereas the setpoint data on the Activity tab specifies the actual values. Therefore, for each defined zone, this parameter varies [107].

4.2 Simulation analysis

In order to improve the energy performance of the office building, a series of measures for building envelope and systems were defined and implemented in the model that was previously generated.

For each measure, a separate .dsb file has been created and simulated to obtain different energy performance results and to compare them to the reference state of the building.

In order to determine the energy rating level of the building, the EPC (Energy Performance Certificate) is calculated by adding the Heating, Cooling, Lighting and DHW obtained in the simulation for the whole year, divided by the total area of the building and multiplied by the power energy factor as (2) shows. As defined for the official energy performance software for Malta, power energy factor in this case is 3.45. The result produces the overall primary energy of the building in kWh/m²/year and this represents the energy rating of the building as would appear on a real energy performance certificate.

$$\frac{(Lighting + Heating + Cooling + DHW)}{Area} * 3.45 \tag{2}$$

The reference scenario has yielded a primary energy rating of 161 kWh/m²/year for the actual building.

To calculate the total electricity consumption from the simulation during the year, it is necessary to add up all the systems that consume electricity in the building, i.e., lighting, heating, cooling, DHW and equipment. This sum yields a result of 138.682 kWh per year, which when compared to the actual consumption provided by the company of 180.148 kWh, yields a percentage difference of 23%. This could be due to factors like those caused by human nature that DesignBuilder cannot contemplate (e.g., leaving doors open when the room is being airconditioned).

4.2.1 Insulation

As a means to determine whether insulating the walls or roof would improve the energy performance of the building, 5 different scenarios are considered to select which alternatives would be most suitable for this building given the materials and climate present in Malta. The different improved construction parameters to be combined and analysed with their improved u-values can be seen in Table 11 below.

Table 11. Insulation construction parameters

Assembly	Material	Thickness (m)	U-Value ($W/m^2.K$)
Insulated thick external wall	Limestone, soft	0.350	0.854 (Originally was 0.999)
	Air gap	0.025	
	Limestone, soft	0.350	
	Gypsum Plastering	0.006	
	Air gap	0.025	
	Gypsum plasterboard	0.01	
Insulated thin external wall	Cement plaster	0.003	1.76 (Originally was 2.511)
	Limestone, soft	0.230	
	Gypsum Plastering	0.006	
	Air gap	0.025	
	Gypsum plasterboard	0.01	
Insulated external roof 1	Bitumen, felt/sheet	0.004	0.240 (Originally was 0.963)
	Roof Screed	0.080	
	Limestone, semi-hard	0.080	
	Concrete, Reinforced (2% steel)	0.200	
	Plaster (Dense)	0.003	
	Air gap (downwards)	0,025	
	XPS Extruded Polystyrene - CO2 Blowing	0.012	
	XPS Extruded Polystyrene - CO2 Blowing	0.1	
	Roof screed	0.08	
Insulated external roof 2	Bitumen, felt/sheet	0.004	0.370 (Originally was 0.963)
	Roof Screed	0.080	
	Limestone, semi-hard	0.080	
	Concrete, Reinforced (2% steel)	0.200	
	Plaster (Dense)	0.003	
	Air gap (downwards)	0,025	
	XPS Extruded Polystyrene - CO2 Blowing	0.012	
	XPS Extruded Polystyrene - CO2 Blowing	0.05	
	Roof screed	0.08	

4.2.1.1 Walls

By applying the different measures as explained in Table 11 it is clear that wall insulation using 0.01 m of internal gypsum board yields around 11% savings in space heating and almost no savings for cooling (1% savings). Figure 30 and Figure 31 show the monthly electricity supply on heating and cooling for the actual configuration and for the building including wall insulation. While if one is to increase the level of insulation the benefits are marginal and do not justify further insulation.

Calculating the EPC for wall insulation, a value of 159 kWh/m^2/yr is obtained, 1 kWh/m^2/yr lower than the actual building.

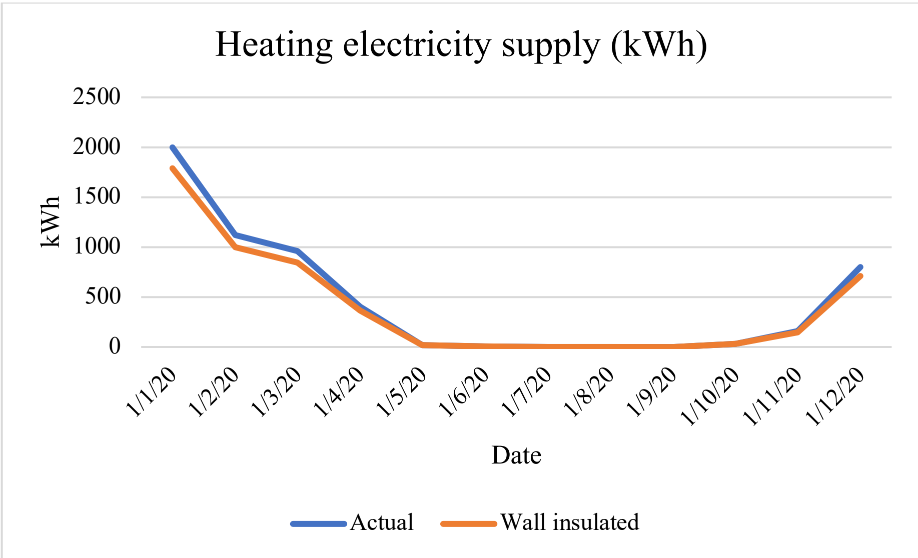

Figure 30. Heating electricity supply for the actual building and the building with walls insulated

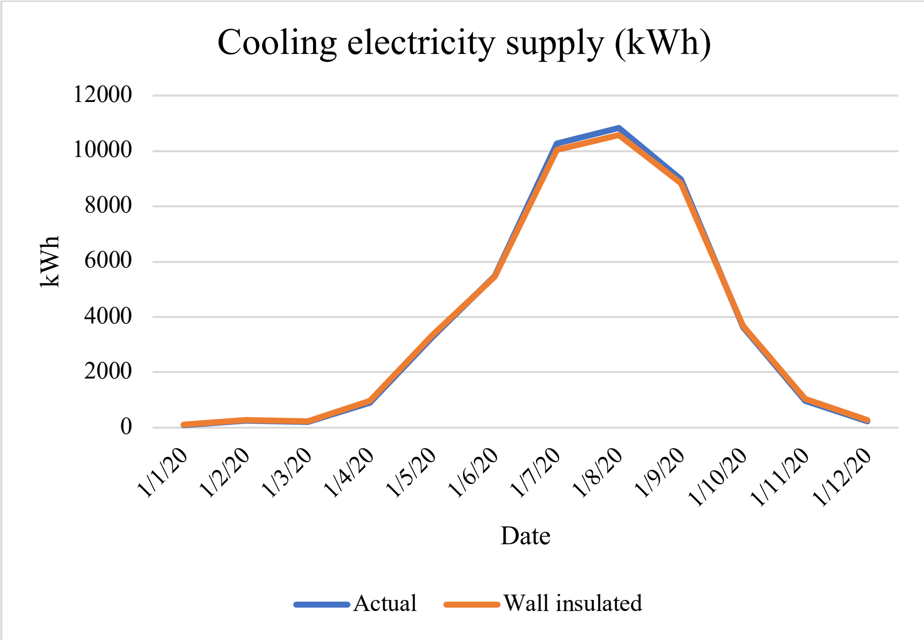

Figure 31. Cooling electricity supply for the actual building and the building with walls insulated

The reason why cooling has not dropped as much as heating is because the solar gains through windows and the heat generated by occupants has not changed and therefore the cooling load remained almost constant even when insulation was introduced. Moreover, due to the high heat capacity of the walls (being made of stone), the addition of insulation to the thick walls will not make any significant difference in their performance, while the addition of insulation to the single external walls does make an improvement but the total area of external single walls is much lower than the total area of double walls.

On the other hand, during winter a number of factors affect the heating load such as infiltration, besides heat losses from the walls have an added impact. Therefore, the improvement in winter is better than in summer for the same wall insulation material.

4.2.1.2 Roof

The fundamental factors that affect the cooling and heating loads of a structure are heat gains and losses through building surfaces. The more solar radiation reaches the building fabric's surface area (roof, walls, windows, and floor), the more heat gains are generated.

The roof, as the building surface with the maximum sun exposure, accounts for the majority of heat uptake in the structure especially in summer unless it is encroached by taller buildings on either side.. As a result, the quantity of solar heat gain obtained by the roof must be decreased by combining roof construction options. The temperature, the thickness and quality of insulation, maintenance and surface reflectivity all have an impact on energy use.

4.2.1.2.1 Full building analysis

When analysing the two possible scenarios for roof insulation, the following comparisons have been obtained with respect to the current situation of the building.

Roof insulation 1

When adding 0.1 m of Extruded Polystyrene, a reduction on heating electricity of 12% is achieved. On the other hand, cooling electricity savings were 4% less compared to the current situation.

Roof insulation 2

In this scenario insulation by means of 0.05 m polystyrene produces heating electricity savings of 10% and 3% on cooling electricity, which are slightly lower than the first roof insulation scenario.

In Figure 32 and Figure 33 monthly heating and cooling energy consumption for both of these scenarios are shown.

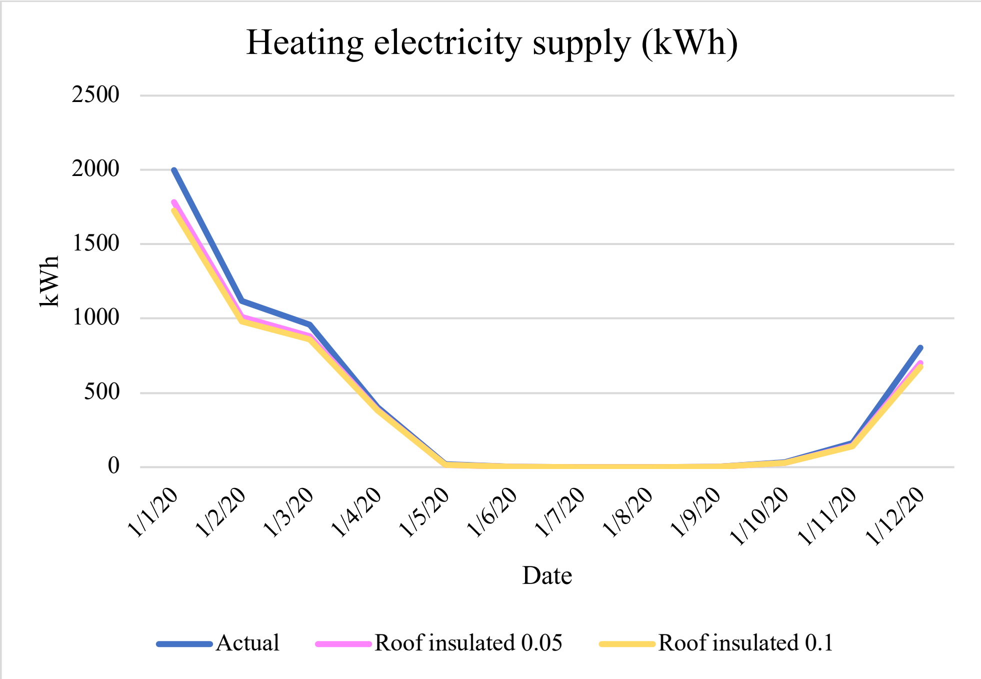

Figure 32. Roof insulation heating electricity supply

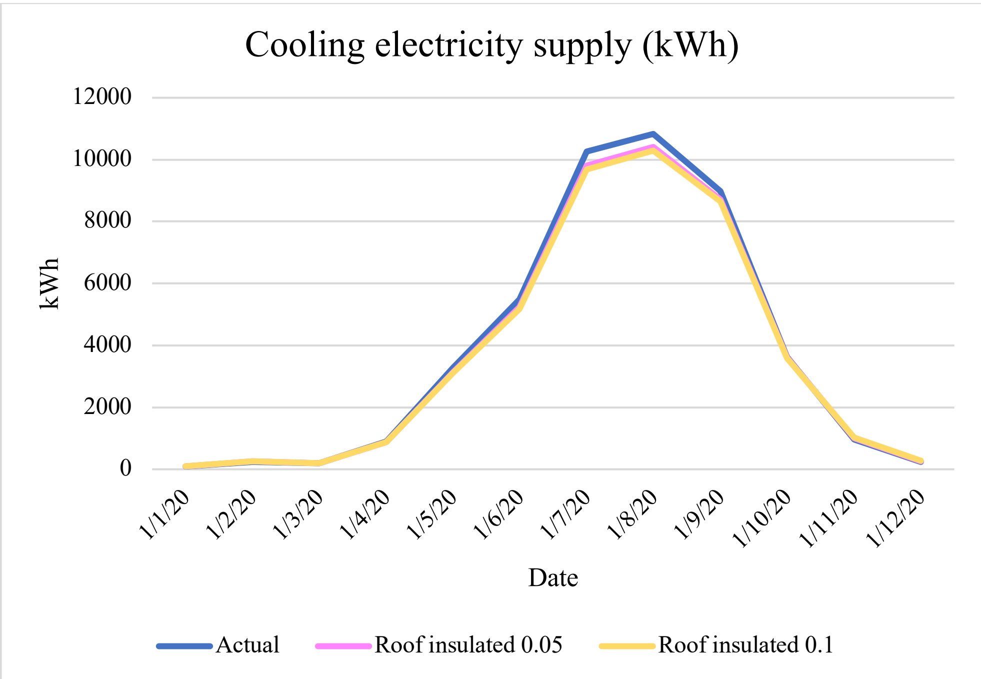

Figure 33. Roof insulation cooling electricity supply

4.2.1.2.2 Upper floor analysis

For a more specific analysis, the area that would be most affected by this measure, i.e., the zones under the roof of the top floor, is analysed and the following improvements are obtained for each scenario.

Roof insulation 1

On the upper floor, the addition of 0.1 m of Extruded Polystyrene, results in savings of 27% in heating and 17% in cooling.

It is significantly higher than the improvement for the whole building as it is an area that is directly affected by the insulation of the roof.

Roof insulation 2

Insulation by adding of 0.05 m polystyrene a reduction of 21% on heating electricity is achieved while cooling electricity consumption drops to 12% compared to the actual building configuration.

In Figure 34 and Figure 35 monthly zone heating and cooling energy consumption on the upper floor of the building for both of these scenarios is shown.

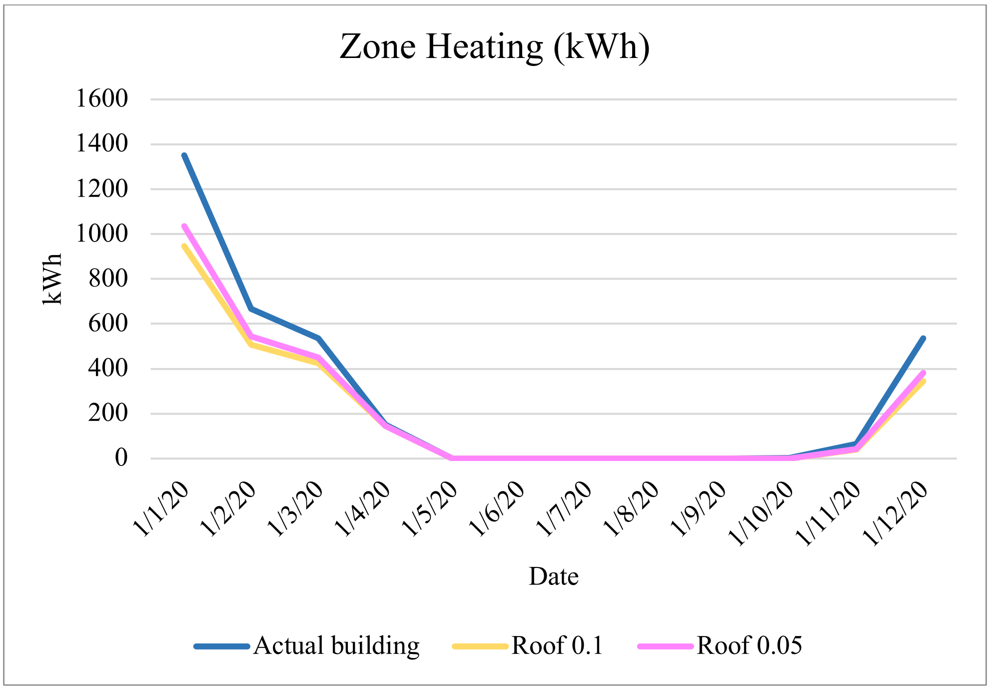

Figure 34. Zone heating upper floor roof insulation

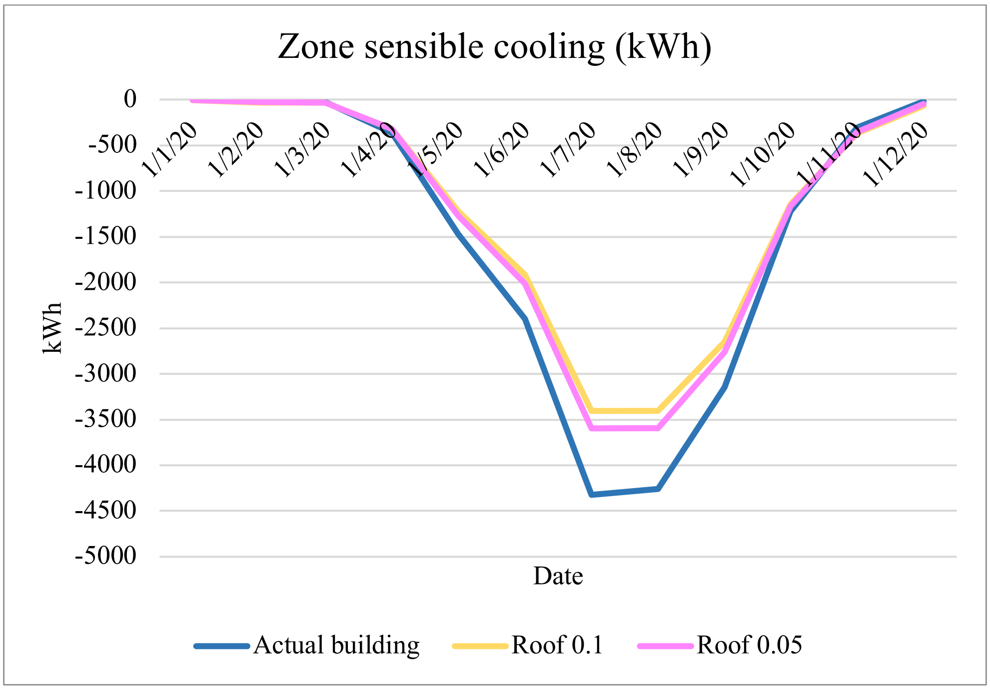

Figure 35. Zone sensible cooling upper floor roof insulation

After analysis and comparison of the two scenarios, as Table 12 shows the insulation thickness that yields the greatest benefits due to the significant reduction in electricity costs for both heating and cooling is the addition of 0.1 m of Extruded Polystyrene.

Table 12. Roof insulation electricity improvement by area

Measure	Area	Heating improvement	Cooling improvement
0.1m XPS	Entire Building	12%	4%
	Upper floor	27%	17%
0.05m XPS	Entire Building	10%	3%
	Upper floor	21%	12%

Therefore, considering these results, the other scenario (0.05 m polystyrene) is ruled out of future analysis.

4.2.1.3 Wall and roof

Finally, the consequences of insulating walls and roof together are analysed exclusively for a roof insulation consisting of 0.1 m of XPS as the other scenario has been discarded above.

By insulating the two components, a significant saving on heating energy of 23% is achieved while a reduction of 5% on cooling energy is made.

Monthly energy consumption comparison to the actual building can be appreciated in Figure 36 and Figure 37.

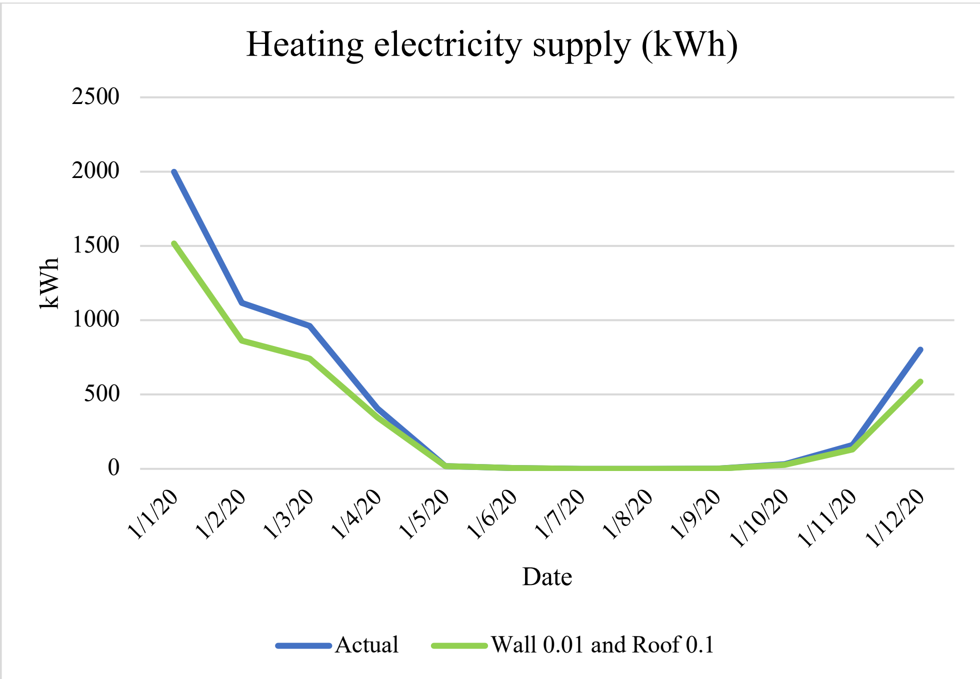

Figure 36. Heating electricity wall and roof insulation

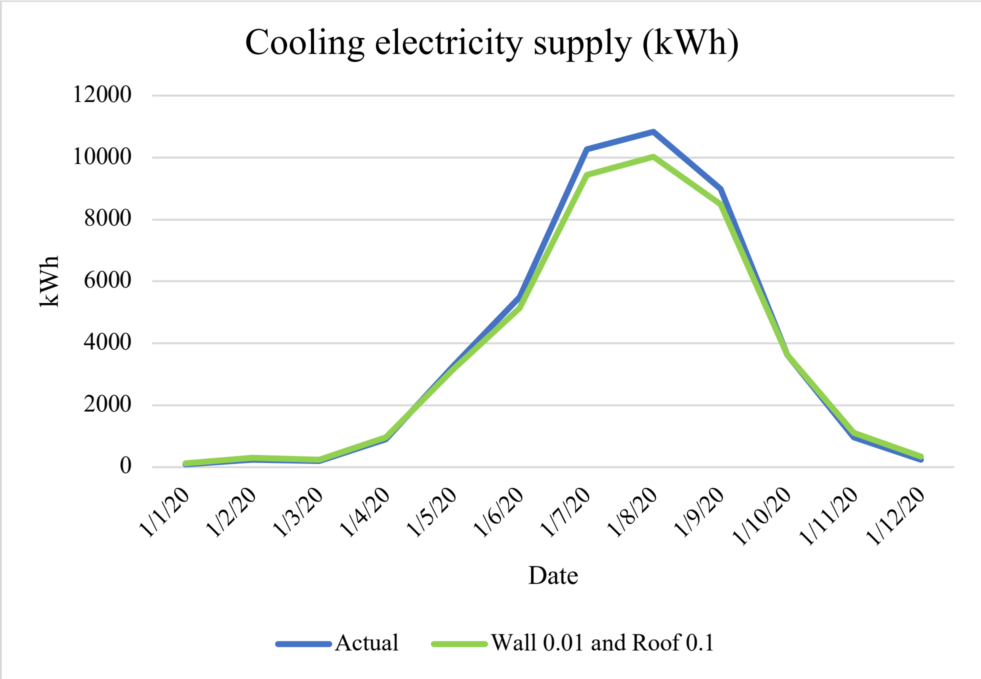

Figure 37. Cooling electricity wall and roof insulation

Analysing the non-discarded scenarios in the same graph as Figure 38 and Figure 39 show, it is demonstrated that insulating both, single walls with 0.01 m Gypsum plasterboard insulation, and roof with an insulating material thickness of 0.1 m is the option that provides best results in terms of energy saving.

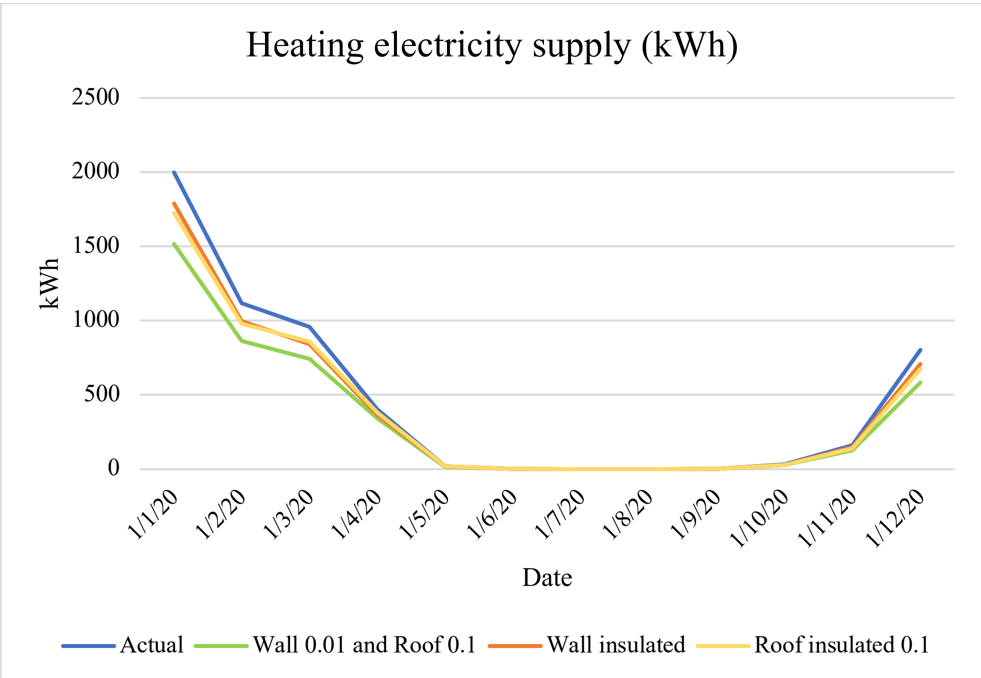

Figure 38. Heating electricity supply comparison of scenarios

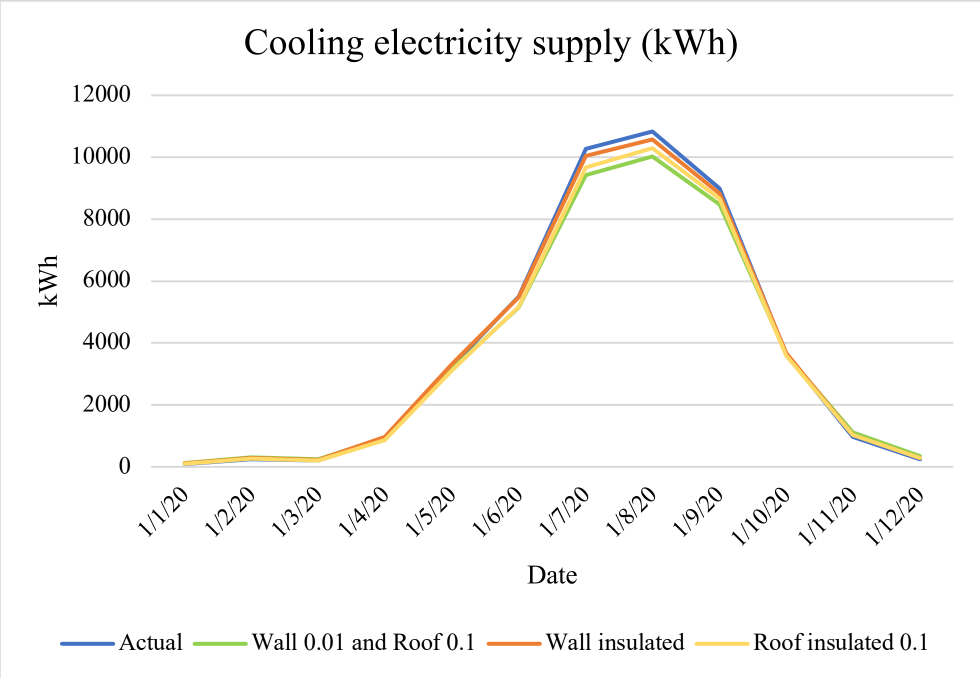

Figure 39. Cooling electricity supply comparison of scenarios

After analysing and comparing each scenario, the measure that delivers the biggest improvements in the whole building due to considerable reductions in electricity costs for both heating and cooling is wall insulation for all external walls adding 0.01 m of insulation material and roof insulation by adding 0.1 m of Extruded Polystyrene, as shown in Table 13.

Table 13. Insulation results comparison

Insulation	Heating improvement	Cooling improvement	Primary energy rating (kW/m^2.year)
External walls	11%	1%	159
Roof 0.1 m XPS	12%	4%	156
Roof 0.05 m XPS	10%	3%	157
Wall 0.01 m Gypsum plasterboard + Roof 0.1 m XPS	23%	5%	154

This outcome requires substantial retrofitting to the actual building fabric while also demanding a complete change in the mentality and perception of what is acceptable for such significantly historical buildings. It should therefore be considered whether the energy benefit they produce would outweigh the other disadvantages.

4.2.2 Shading

Installing shading devices in places where the sun hits can produce energy savings as it can lead to a decrease in the use of cooling Energy Systems. To prove if shading can make a substantial difference on energy saving, different scenarios depending on the orientation of the building and the type of shading device installed are simulated as Table 14 shows.

Table 14. Shading types and areas

Shading Device	Area
Overhangs	Southeast
	Southwest (Strait St.)
	Northwest (Old Bakery St.)
	All building
	Kitchen
	Circulation area
Louvres	Southeast
	Southwest (Strait St.)
	Northwest (Old Bakery St.)
	All building
	Kitchen
	Circulation area

The areas designated as Kitchen and Circulation area are indicated on the plan in Figure 40 and Figure 41, both of which have been selected as having a high percentage of window to wall ratio in various orientations, which could cause overheating when the sun passes through throughout the year.

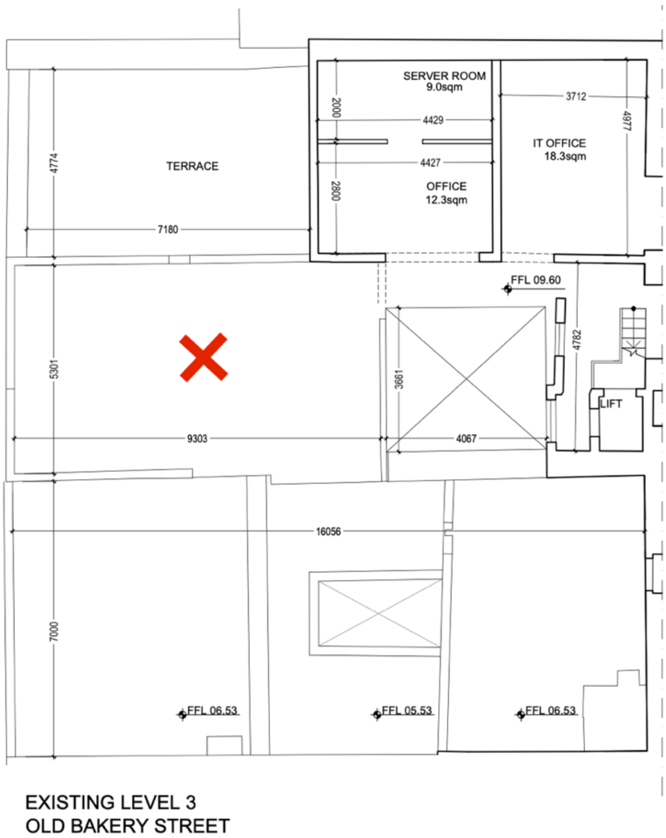

Figure 40. Kitchen location on plan

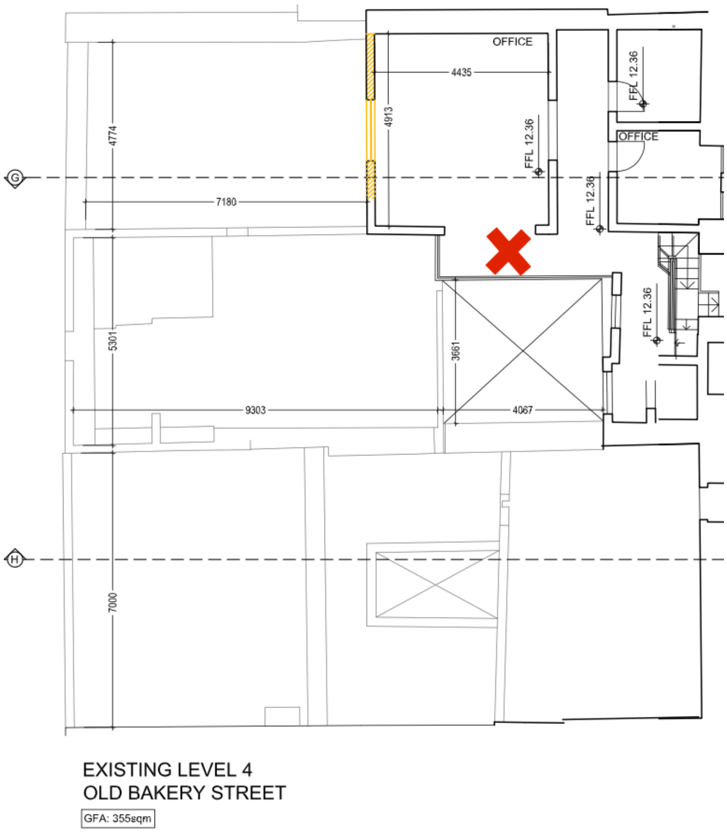

Figure 41. Circulation area location on plan

To configure this device in DesignBuilder, it is necessary to go to the Openings section, open the Shading drop-down menu and select the preferred shading mode (Window Shading or local Shading) Figure 42 shows shading configuration in the simulation.

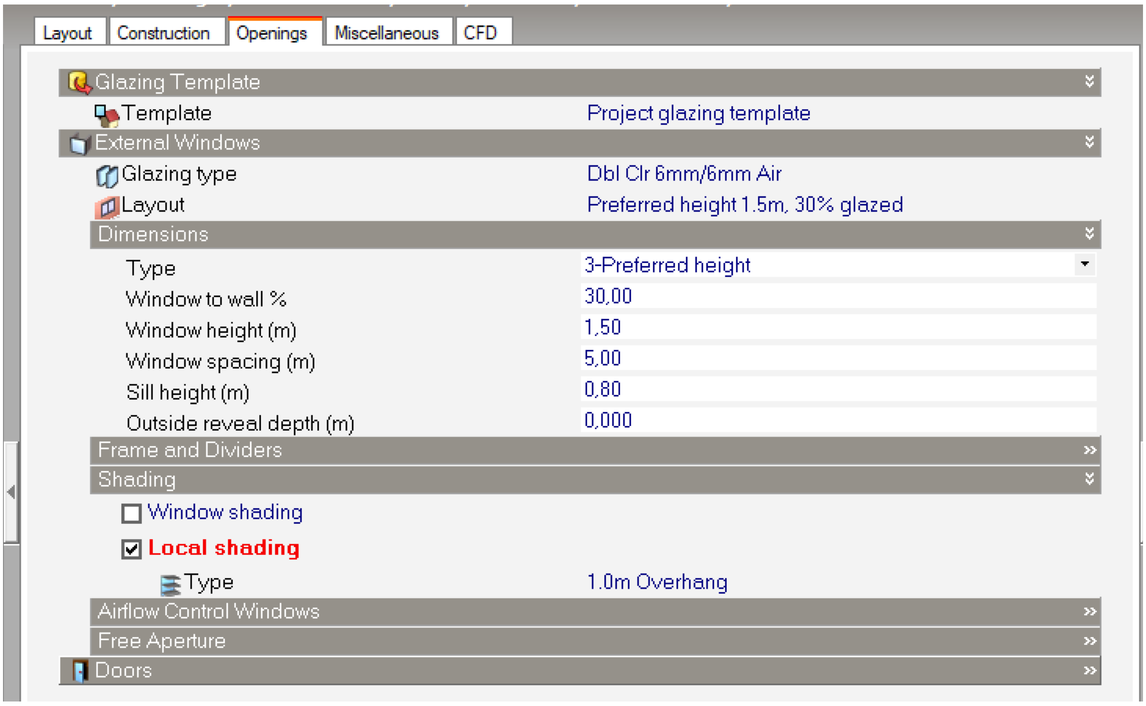

Figure 42. Shading configuration on DesignBuilder

In this case, local shading will be used to analyse two possible scenarios, installing 1.0m overhangs or 1.0m louvres on the outside of the openings of the building.

4.2.2.1 Overhang shading

This type of shading consists of a horizontal device located on top of the window to create a shadow that prevents sun from hitting the building. Figure 43 and shows the shape and configuration of these shading devices used in the simulation.

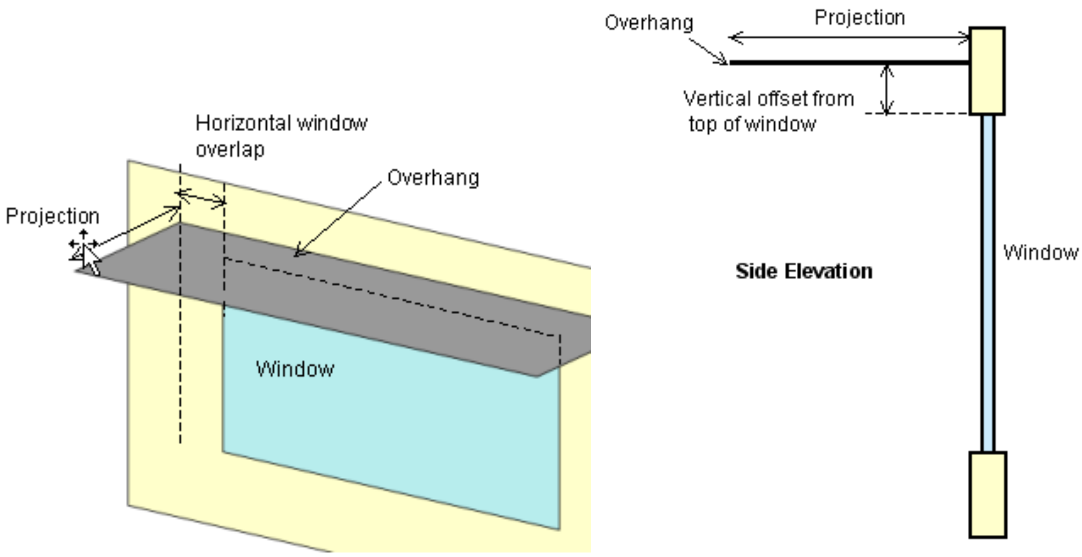

Figure 43. a) Overhang shading front elevation. **b)** Overhang shading side elevation

After simulating the different scenarios on overhangs shading, the improvements compared to the current situation are as shown in the Table 15 below.

Table 15. Overhang shading improvement by area

Area	Heating improvement	Cooling improvement	Lighting improvement	Solar gains reduction
Southeast	-2%	3%	0%	10%
Southwest (Strait St.)	0%	1%	0%	4%
Northwest (Old Bakery St.)	-1%	1%	0%	5%
All building	-3%	5%	0%	20%
Kitchen	0%	8%	0%	51%
Circulation area	-13%	28%	0%	26%

Due to its location in the northern hemisphere, Malta receives the greatest sunlight during the summer, when the sun is also at its highest elevation. As a result, the higher, or more vertical, the arc of the sun, the longer the shadow cast by the building overhang along the face of the Wall, and in this way overhangs are most effective around midday on summer for south facing windows.

The sun rises in the northeast and sets in the northwest in Malta during the summer and rises in the southeast and sets in the southwest during the winter. After the summer equinox, it begins to move further south every day until it reaches its lowest south at the winter equinox, at which point it begins to rise further north each day. (The equinoxes, June 21st, and December 21st, correspond to the maximum and minimum azimuths.).

Therefore, it can be explained that the results obtained do not produce significant improvements as the sun hits the south-west façade the most at sunset in winter when the overhangs would not be useful, and one has to think of another way to shade the windows.

4.2.2.2 Louvres

A louvre is a vertical covering made up of narrow, sloping slats secured in a frame. They provide screening as well as shade from the sun and protection from wind and rain [104]. Figure 44 shows the structure that makes up louvres in the simulation.

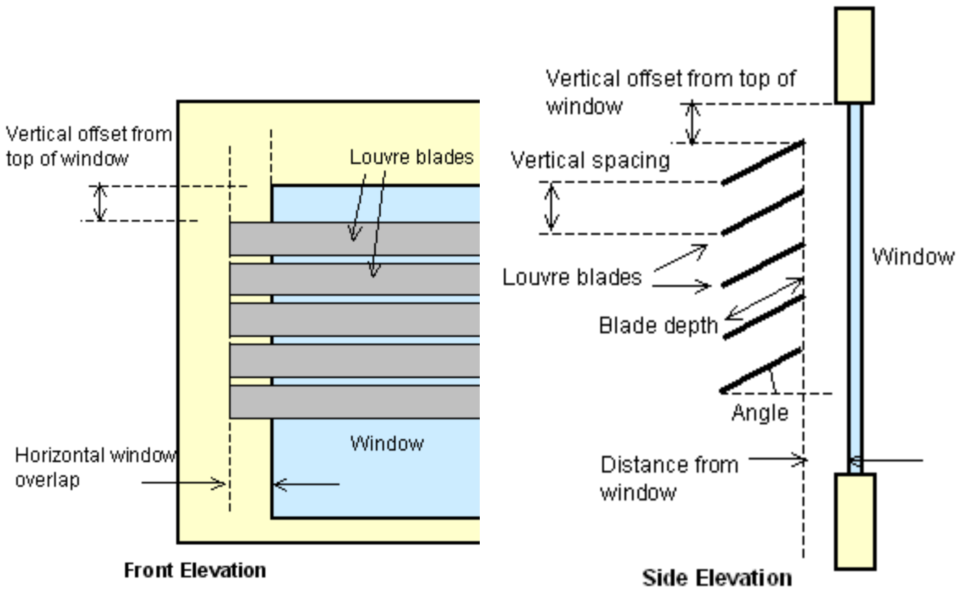

Figure 44. a) Louvre shading front elevation. **b)** Louvre shading side elevation

Improvements over the current building resulting in the addition of louvres in each area are shown in Table 16.

Table 16. Louvre shading improvement by area

Area	Heating improvement	Cooling improvement	Lighting improvement	Solar gains improvement
Southeast	-5%	5%	0%	20%
Southwest (Strait St.)	-1%	1%	0%	5%
Northwest (Old Bakery St.)	-7%	7%	0%	29%
All building	-8%	8%	0%	34%
Kitchen	0%	4%	0%	29%
Circulation area	-31%	43%	0%	43%

Comparing the primary energy rating for the two scenarios, Table 17 shows that installing louvres generates better results for all orientations studied except for the kitchen, where overhangs perform best.

Table 17. Primary energy rating for shading types by orientation of shading

Measure	Primary energy rating kWh/m²/yr	
	Overhangs	Louvres
Southeast shading	159	157
Southwest shading	160	160
Northwest shading	160	156
Full building shading	157	155

As indicated above, the areas in which installing shading would produce the best results would be the kitchen or circulation area, so it is concluded that the most favourable measures are to install louvres in one or both of these areas.

Analysing solar gains for this measure is of great relevance, as it is the increase in thermal energy of a space, object, or structure as it absorbs incident solar radiation. Installing shading means that the sun does not shine directly on the windows, an action that could generate benefits in terms of thermal comfort, cooling Energy saving.

Figure 45 shows comparative graphs of the solar gains of the current building compared to the two kitchen shading scenarios.

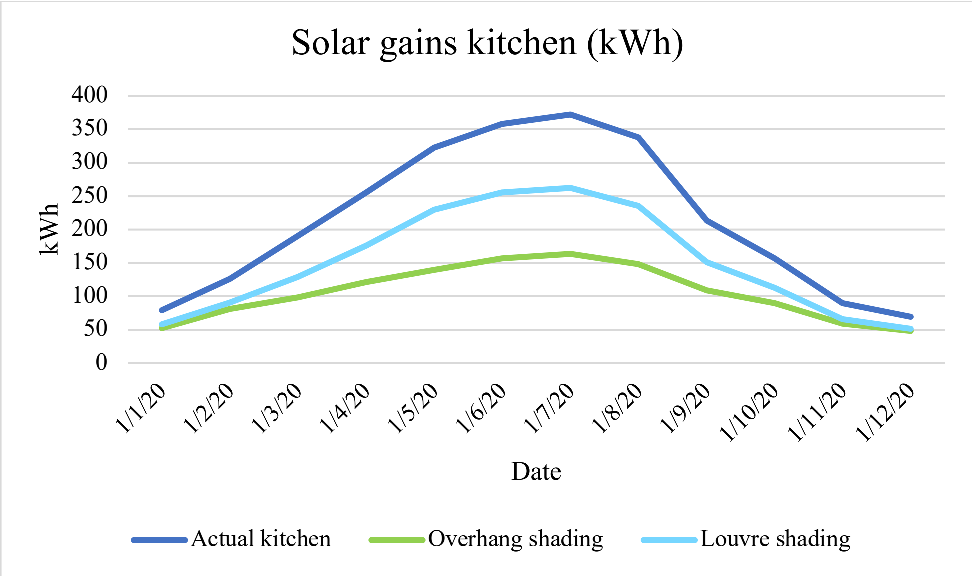

Figure 45. Kitchen solar gains shading comparison

Installing overhangs in the kitchen is more favourable than louvre shading. This is due to the fact that as indicated above, the sun in the Maltese summer rises form the northeast and sets in the northwest. The windows present in the kitchen are oriented to the southwest, northeast and northwest, meaning that in summer the sun hits constantly on the kitchen. As it was also mentioned, overhangs are most useful when the sun is at its highest, i.e., in summer, so that would make them convenient for this zone.

In Figure 46 a comparison is made to see the effect of shading inside the kitchen using overhangs or louvres during summer at 12 pm and at 5 pm, these times being the time of generally higher temperatures and the time of early evening.

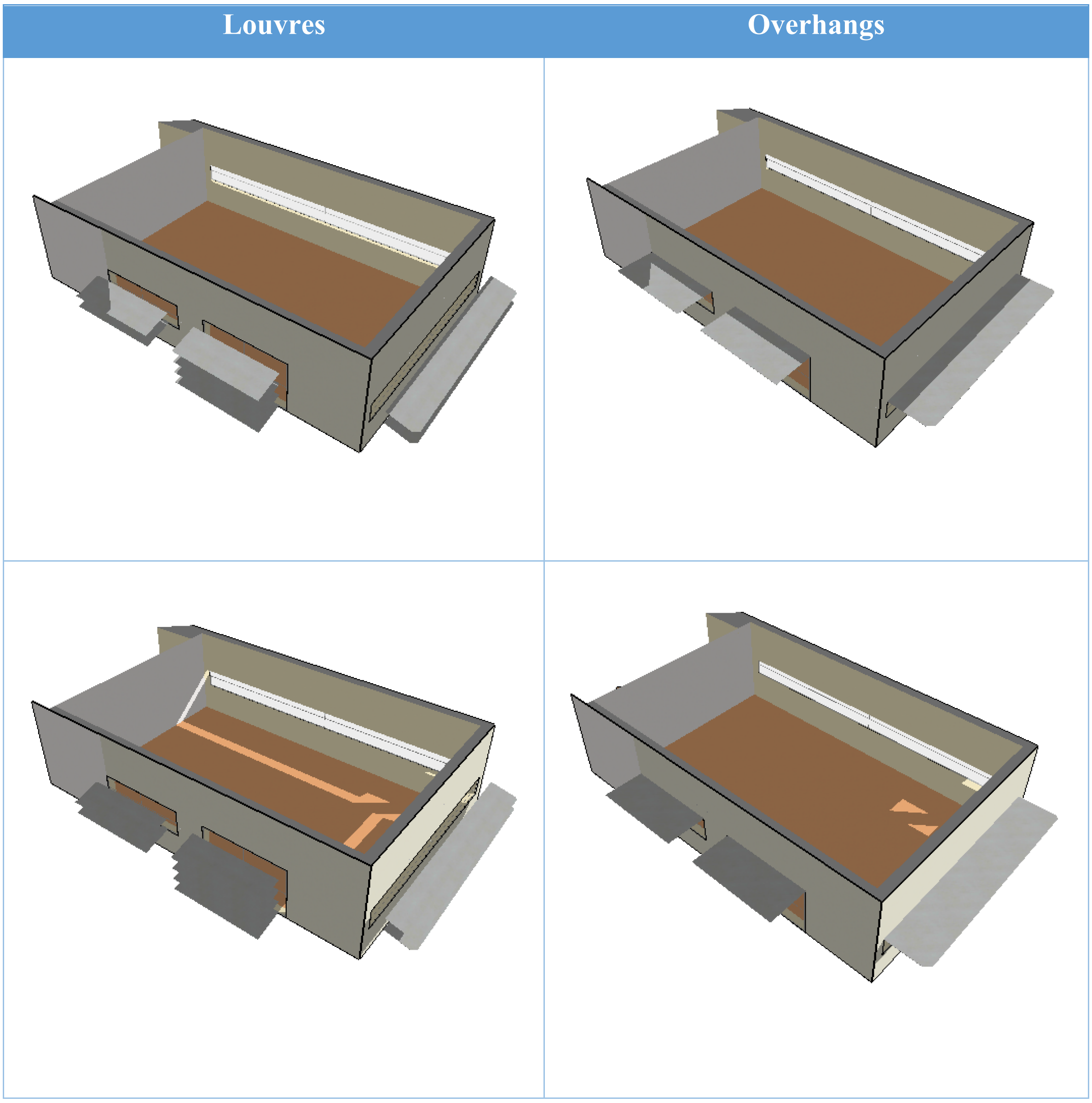

Figure 46. Kitchen shading visualisation summer

As it was already stated, overhangs produce slightly higher shading for this room throughout the whole day, and this happens also during a normal day of Winter at 12 pm and 3 pm as Figure 47 shows.

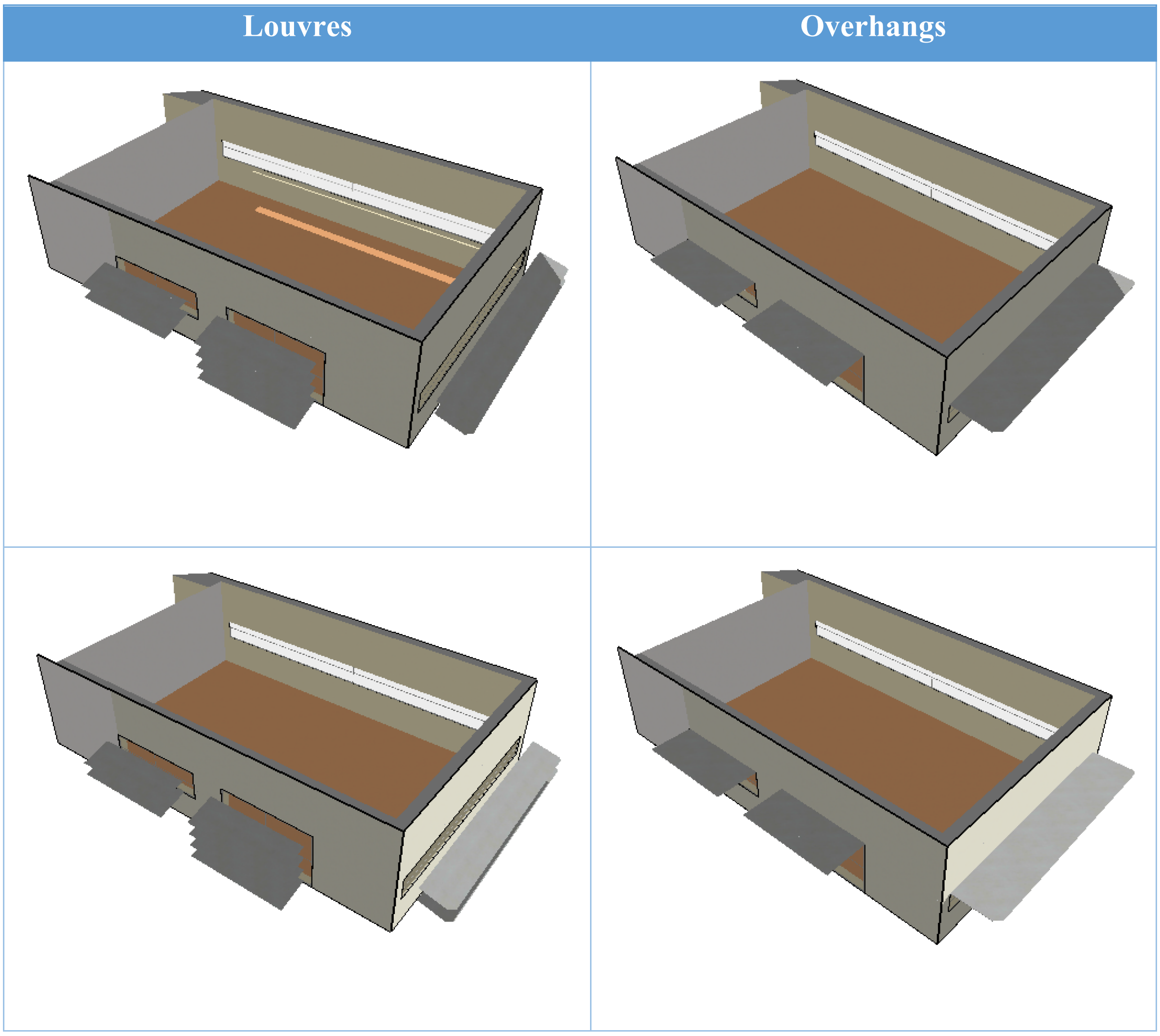

Figure 47. Kitchen shading visualisation winter

Solar gains in the circulation area for both types of shading are compared to the actual building in Figure 48.

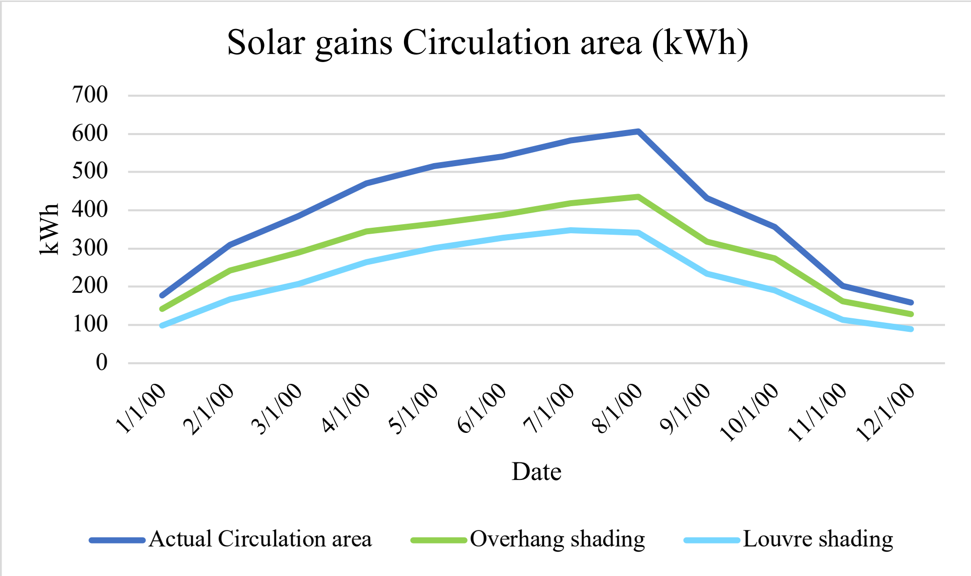

Figure 48. Circulation area solar gains shading comparison

Windows in this zone are oriented to the northwest and southwest, and this influences overhangs to perform worse than louvres because in this orientation the sun only strikes at dusk, i.e., when the sun shines at its lowest point. As the overhangs are arranged completely horizontally and as already mentioned, work best when the sun is higher, they would not be the most appropriate for this area, on the other hand, using louvres would be more convenient as the inclination with which they are arranged makes them suitable for a wider range of sun heights.

To visually analyse the effect of the louvres and overhangs in this area, Figure 49 shows the effect they would produce during summer at 5 pm (top) and winter (bottom) at 3pm, in this case, it is not useful to analyse their effectiveness during the morning since, being oriented to the southwest and northwest, the sun only strikes during the afternoon.

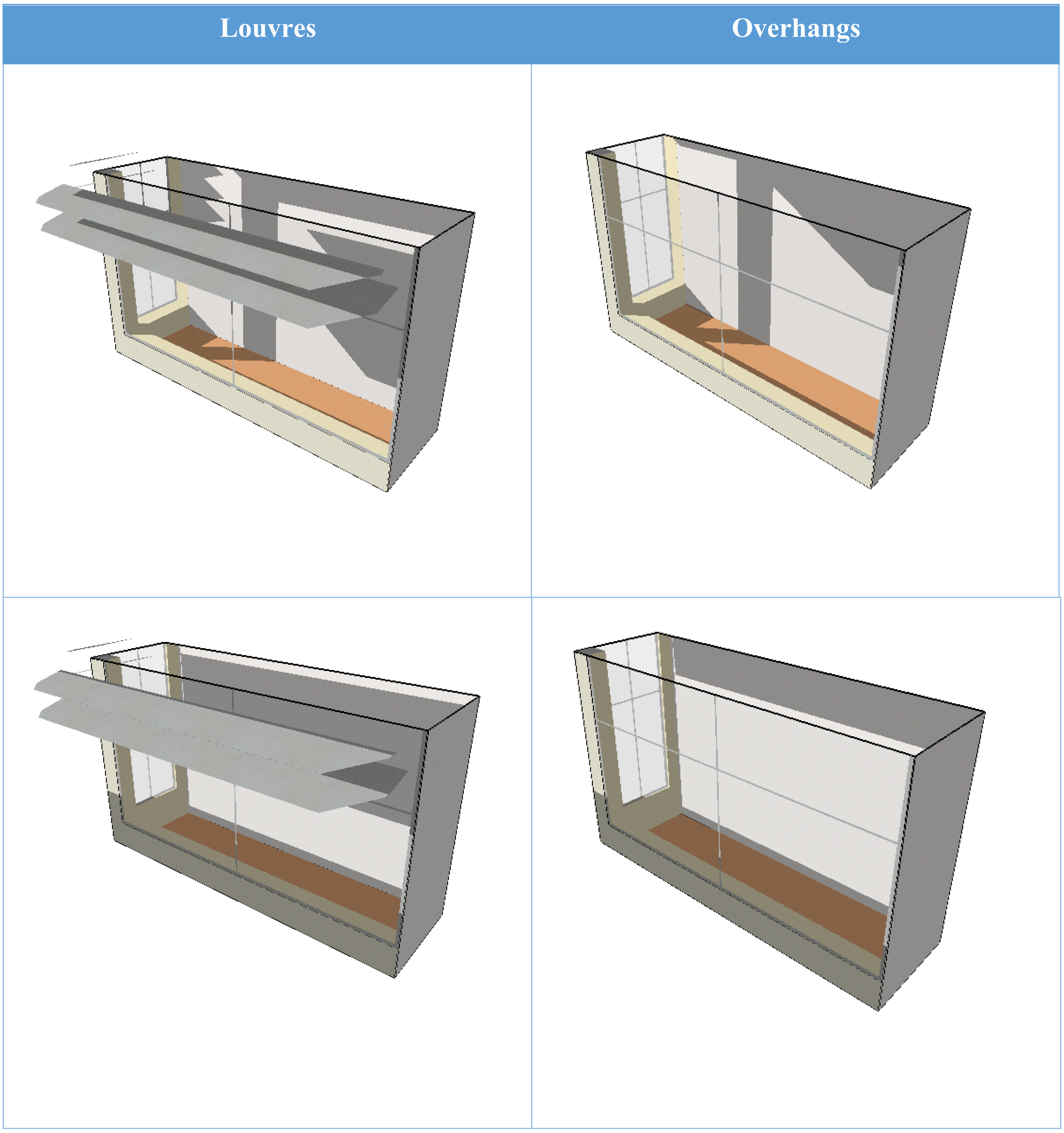

Figure 49. Circulation area shading visualisation afternoon winter and summer

As previous analyses indicate, louvres generate more shading than overhangs, this is of special necessity in summer.

Installing shading in the selected areas does not compromise the historic aesthetics of the façade as the façade on which they are located is not of that nature and is not visible from any of the access streets.

4.2.3 Low emissivity windows

Low-E glass windows have a microscopically thin transparent coating that reflects heat. This coating keeps the temperature consistent by reflecting the interior temperatures back inside, this way, Low emissivity windows are able to keep the heat in during cold winter months, and let it bounce off during warm summer months.

If all openings in the existing building were to be equipped with Low-E solar film on the outside surface, it would result in a primary energy rating of 160 kWh /m^2*year, only 1 point lower than the actual case. This is because improvements in electricity consumption are almost negligible as Table 18 shows. This is mainly due to the fact that many windows actually do not see much sun at the lower levels of the building and therefore the overall impact would be low.

Table 18. Low Emissivity windows improvement

Measure	Heating improvement	Cooling improvement	Lighting improvement	Solar gains reduction
LoE windows	1%	1%	0%	11%

Figure 50 shows the monthly consumption in both scenarios for solar gains energy consumption, where the improvement is most significant, and therefore, graphically distinguishable.

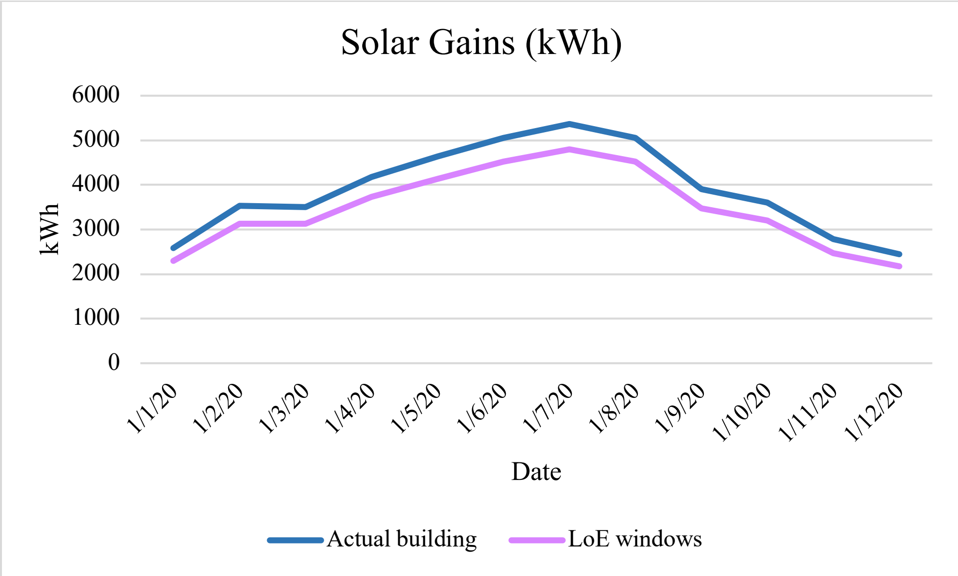

Figure 50. Solar gains Low Emissivity windows comparison

Another way to analyse window effectiveness in admitting both light and solar heat is using two indicators, Visible Transmittance (VT) and Solar Heat Gain Coefficient (SHGC). Sufficient daylight would be admitted while substantial amount of solar radiant heat gain will be blocked by keeping VT high and SHGC low.

Visible Transmittance is a fraction of the visible sunlight spectrum transmitted through a window weighted by the sensitivity of the human eye. More visible light is transmitted by a product with a higher VT. The value of VT is a number between 0 and 1 generally ranges from 0.4 to 0.7 [105].

The fraction of solar radiation allowed through a window, door, or skylight known as the solar heat gain coefficient (SHGC). The lower the SHGC, the less solar heat it transfers and the more effective it is in shading.

During the winter, a window with a greater SHGC rating is more useful in retaining solar heat. To reduce cooling loads in summer, windows with a lower SHGC rating would be most effective as they block sun heat gains [105].

To compare both coefficients in the two different scenarios, Table 19 is shown below

Table 19. VT and SHGC in actual and LoE windows comparison

	Visible Transmittance (VT)	Solar Heat Gain Coefficient (SHGC)
Actual clear double-glazing windows	0.781	0.700
Low Emissivity windows	0.721	0.637

The actual building equipped with clear double-glazing windows has a VT of 0.781 while the simulated model using LoE windows slightly decreases to 0.721.

As it was stated above, a higher VT allows more visible light to enter the room, Therefore, in this respect, current windows would be better in light transmission. VT is lower in LoE windows as the coating added to them causes the amount of light they transmit to reduce slightly.

SHGC takes a value of 0.700 for the current clear double-glazing windows whereas LoE windows possess a rating of 0.634. Effectivity on reducing cooling electricity would be higher on Low Emissivity windows, as mentioned above, the lower the value, the better the performance at reducing heat gains.

As it has been explained, improvement by adding a solar film to the existing windows is substantially low also due to the fact that climate in Malta is notoriously stable, with internal temperatures generally differing by less than 10 degrees from the exterior. This can be translated into the fact that highly insulated windows may not be the most suitable for a climate such as that of Malta as they involve a high cost, and their benefits would not be fully exploited.

4.2.4 Desk lamps

The addition of auxiliary lamps on desks in offices could provide light in poorly lit offices and solve problems such as those presented in 4.3.1 below, but it would also lead to an increase in electricity costs for lighting as shown in Table 20 below.

Table 20. Desk lamps improvement

Measure	Heating improvement	Cooling improvement	Lighting improvement
Desk lamps	38%	-24%	-139%

This measure provides improvements exclusively on heating electricity due to the fact that these desk lamps radiate heat when switched on, resulting in less need for heating in the cold months. Conversely, they would increase the need to use air conditioning systems to compensate for this heat release.

Lighting electricity is the main negative aspect of this measure, the electricity consumed in this aspect is more than double that of the current situation of the building, Figure 51 shows a graphical representation of the monthly consumption for both scenarios.

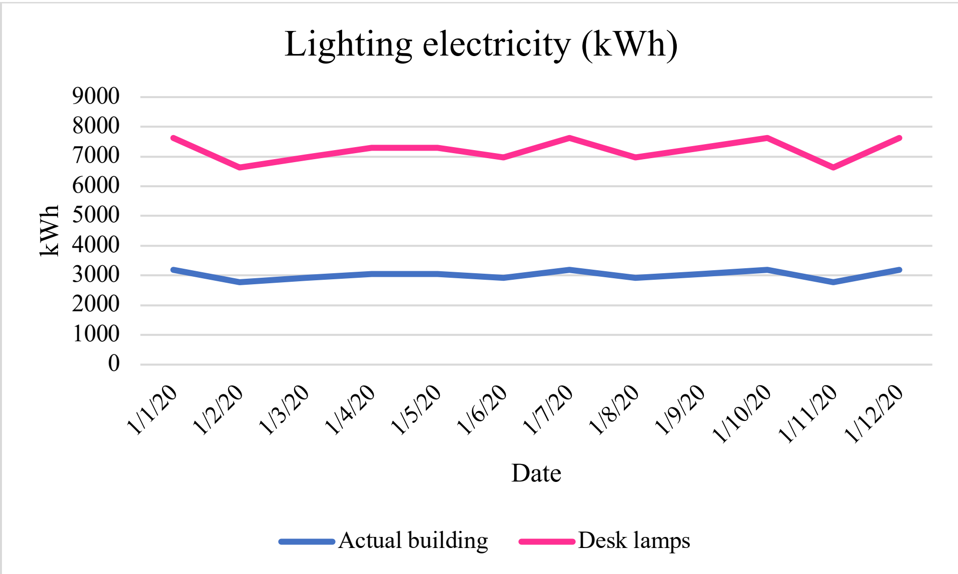

Figure 51. Desk lamps lighting electricity comparison

The primary energy rating rises to 267 kWh /m^2*year, an exorbitant value compared to the current rating.

This would not be a practical option for the whole building, as the electricity costs would skyrocket, and lamps might be placed in offices that are already well-lit. The appropriate approach would be to evaluate those offices where the current lighting is not sufficient and auxiliary lighting needs to be installed. To implement this, the analysis in section 4.3.1 is carried out.

4.2.5 Lighting control

Electric lights can be dimmed or increased depending on the quantity of natural light available. If Lighting control is enabled, illuminance levels are measured at each time step and used to evaluate how much electric lighting may be reduced. The intensity of daylight illuminance in a zone is influenced by sky conditions, sun position, photocell sensor placements, window location, size, and glass transmittance, window shades, and reflection of interior surfaces.

The amount of daylight illuminance, the illuminance set point, the fraction of zones regulated, and the method of lighting control all influence the amount of electric lighting used.

Table 21 shows the percentage of influence of adding Lighting Control to the actual building.

Table 21. Lighting control improvement

Measure	Heating improvement	Cooling improvement	Lighting improvement
Lighting control	-10%	6%	34%

Increase on heating electricity may be due to the fact that the luminaires radiate heat which is reduced when the lighting intensity is regulated at times when maximum illumination is not necessary, thus causing an increase in the need for heating in the cooler months.

Conversely, Lighting Control produces a decrease in cooling electricity consumption because dimming the light intensity reduces the heat radiated by the lamps leading to less need for cooling in the warmer months.

Improvements on electricity used for lighting are due to the fact that as the light in each area is adjusted to the needs of the moment, when there is sufficient light from the sun, the lamps are switched off or dimmed.

Figure 52 shows the clear difference between the two scenarios during the whole year.

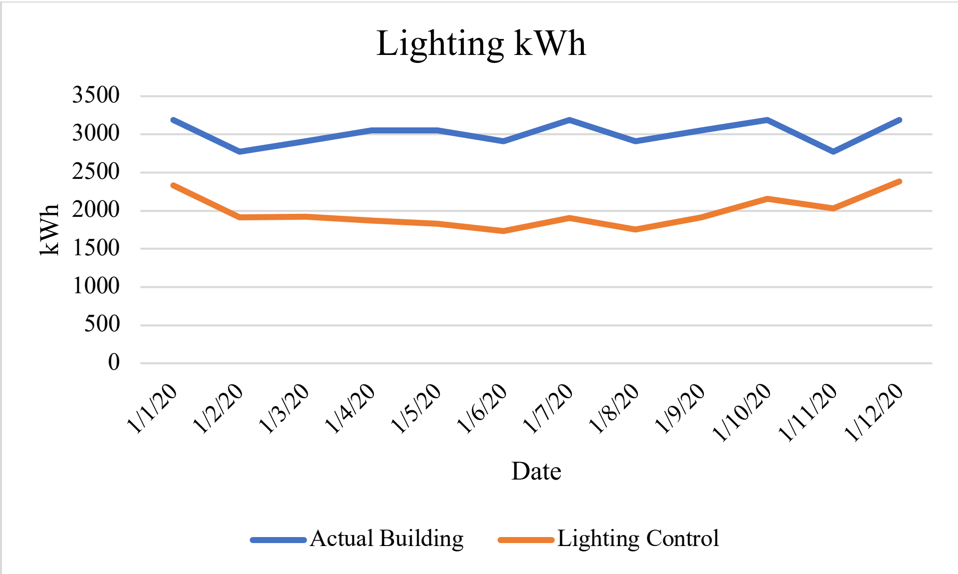

Figure 52. Lighting control lighting electricity comparison

Despite the increase in heating electricity, applying this measure results in benefits in terms of electricity saving, as this rise on electricity supply is compensated by reductions on lighting and cooling as the EPC for this scenario is improved to 135 kWh /m^2*year, 26 kWh /m^2*year less than the actual building scenario.

4.3 Office comfort measurements

In order to determine whether the level of comfort in the offices is optimal, various factors influencing comfort were measured and the following results were obtained

4.3.1 Lighting

It was discovered that illumination was generally adequate in the offices with lux levels ranging between 300 and 500 lux. One particular case was an office in floor Nº2 (see Figure 53) shown in the plan below in Figure 54 where the size of the lamp was disproportionate to the size of the office, causing an excess of light, and the occupant of the office ended up staying in the dark and only using a small desk lamp.

Figure 53. Large lamp in an office of small dimension

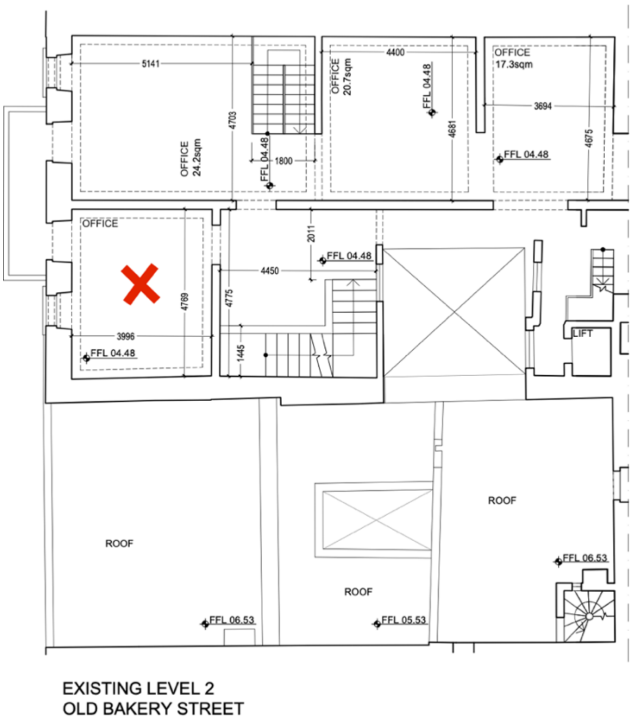

Figure 54. Location of the office containing a disproportionately sized lamp in the plan.

As a consequence of the excess light intensity produced by the large dimensions of the lamp, the occupant would turn the lamp off, causing the lux levels to fall outside the appropriate range as shown in Figure 55.

Figure 55. Lux Meter in a low illuminated office

4.3.2 CO_2 levels

The levels of CO_2 measured in most of the offices were found to be within the safe interval (400-1000 ppm) as can be seen in Figure 56.

Figure 56. Correct levels of CO_2 in an office

However, a single office shown in the plan of Figure 57 indicated high carbon dioxide concentration due to lack of windows (see Figure 58) and lack of mechanical ventilation. This could cause adverse effects on the occupants and even more so in an office where 8 hours are spent daily.

In Figure 59 the CO_2 meter reaching a high value in said office can be observed.

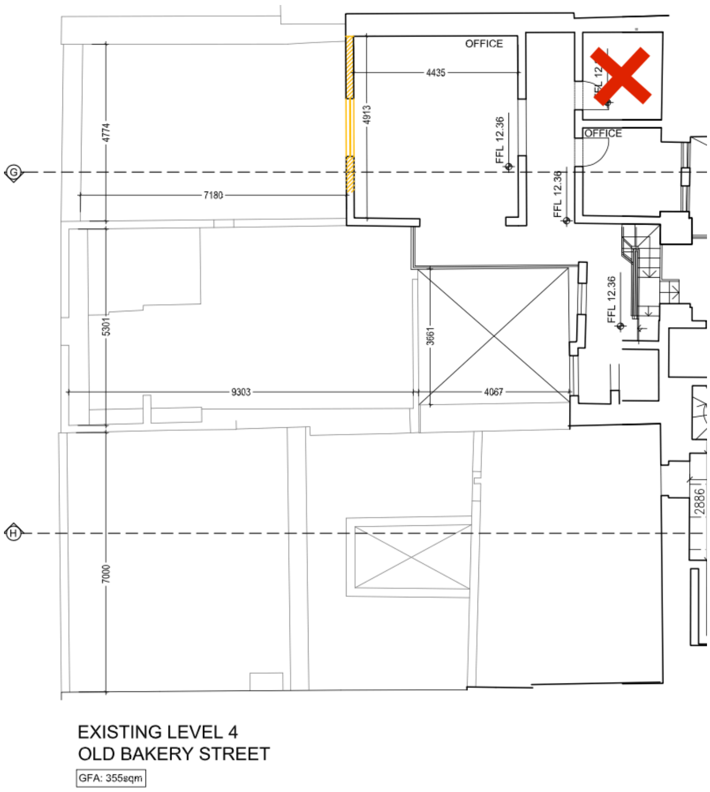

Figure 57. Location of the office with poor ventilation in the plan

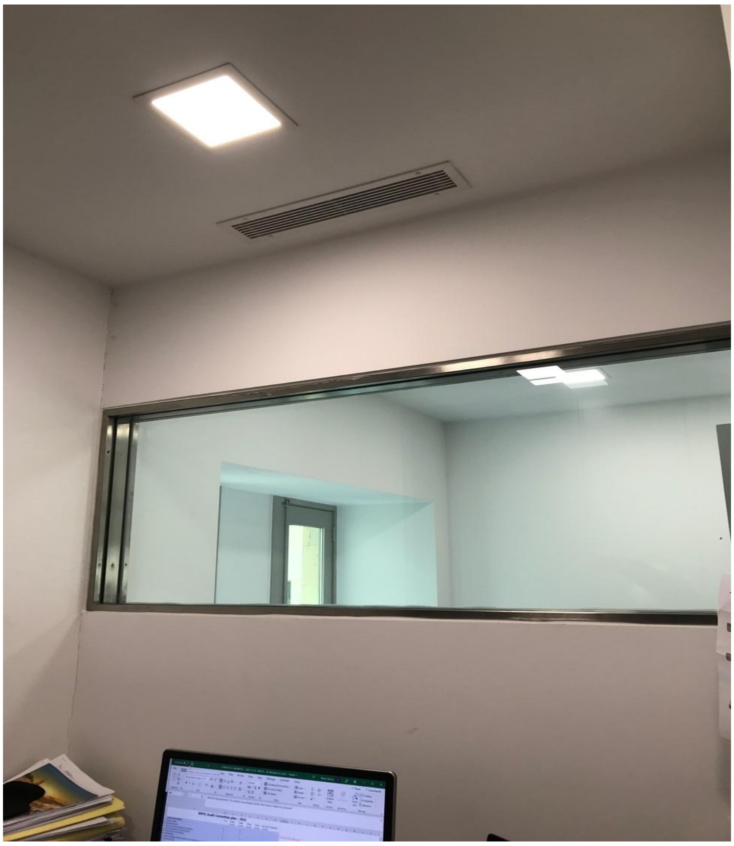

Figure 58. Office with poor ventilation

Figure 59. High concentration of CO2 in an office

4.3.3 Particulate matter and gases counter

In the measurements taken in several offices of the building, different values for particulate matters, TVOC and HCHO were obtained.

In Figure 60 it is shown that the value for PM2.5 and PM10 obtained were within the "Good" rating for AQI. HCHO and TVOC levels were also low enough to pose no risk on human health in the vast majority of the offices.

Figure 60. Particle counter in an office under favourable conditions

However, it was noted that whenever sanitising liquids are used, HCHO and TVOC concentration rise, as shown in Figure 61.

This was found in the offices indicated in the plan in Figure 62 where occupants acknowledged frequent use of hydroalcoholic gel and poor ventilation. Long-term exposure to these volatile emissions can cause respiratory problems.

Figure 61. Particle counter in an office with high levels of TVOC and HCHO

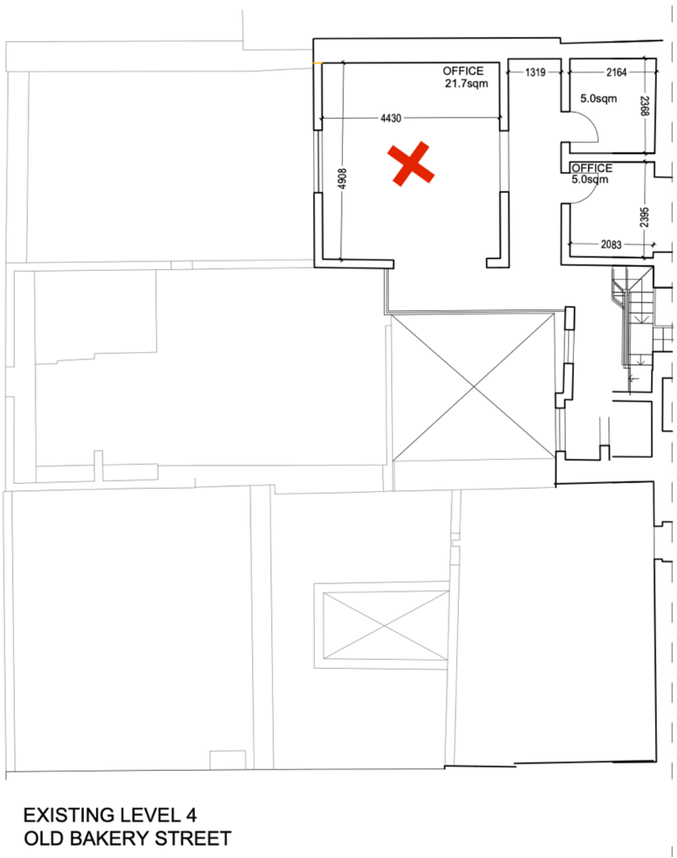

Figure 62. Location of office with high levels of HCHCO and TVOCs in the plan

It is recommended that the use of sanitising liquids is carried out outside the offices (e.g., on balconies or in open spaces) or otherwise it would become necessary to increase airflow to reduce the impact of these pollutants.

5 Conclusion and suggestions for future work

In this project, an energy analysis of a medium-sized office building was carried out. The energy-auditing process included steps such as conducting a walk-through audit to identify on-site issues, measuring certain parameters related to the indoor environment, such as lighting levels and carbon dioxide concentration levels, and determining the building's characteristics, as well as modelling the building using DesignBuilder simulation software.

This tool made it possible to obtain useful information on energy consumption of the different sources in order to determine and evaluate several energy - saving measures to be implemented and optimise the use of energy in the building.

After identification of the measures, these were simulated in DesignBuilder, obtaining several results. On the one hand, the measures relating to the building envelope were analysed. When applying insulation to prevent heat transmission through the surfaces and thus avoid heat loss, 5 possible scenarios were initially considered: Insulating only the external walls with 0.01m Gypsum Plasterboard, insulating exclusively the roof with 0.1m or 0.05m XPS or combine wall and roof insulation for both roof thicknesses. The best performing scenarios were those involving insulating the roof with 0.1m of XPS, the best of which was when combined with wall insulation

By installing Solar Shading to prevent overheating two possible configurations were simulated, overhangs and louvres, with each being evaluated in different areas and orientations of the building. Overhangs produced the most favourable results being installed in the kitchen as the windows in that area face south-east, north-east and north-west, being constantly exposed to the sun in summer, when the sun is highest, and therefore overhangs are most effective. Installing louvres yielded the best results when installed in a circulation area on floor 4 where the sun always hits at dusk, i.e., more horizontally, being louvres more appropriate as they are suitable for a wider range of sun heights.

By simulating replacement of the existing windows with low emissivity windows to keep the temperature constant as they reflect the internal temperature back to the interior, two parameters, Visible Transmittance and Solar Heat Gain Coefficient, were analysed in addition to the electricity consumption. These results indicated that the improvements were too slight to be worth implementing. This may be due to the fact that the climate in Malta is very stable, with temperatures varying very little throughout the day, making this measure too expensive and complicated to implement for the benefits it brings.

On the other hand, measures relating energy systems in the offices were studied. Installing desk lamps would be effective if it was done on a case-by-case basis by assessing each workstation that needed it but implementing this measure across the board meant that the consumption of lighting electricity would be too high.

The lighting control systems showed promising results by considerably reducing the electricity consumption for cooling and lighting, which compensated for a slight increase in heating due to the heat provided by having the light on constantly. Primary energy rating was reduced very significantly.

Finally, when measuring parameters related to indoor environment, poor lighting was detected in one particular office, whose lamp was too large and was eventually not used. In terms of CO_2 levels and ventilation in general, one office was identified as having no external windows and therefore very poor ventilation and a higher CO_2 concentration than is appropriate for humans. Moreover, the frequent use of hand sanitizers for the prevention of the spread of COVID-19 may have been responsible for the high concentration of HCHO and TVOC in another office.

In order to analyse the improvements produced by all measures on the building, a comparison is made as shown in Table 22 in which the most favourable scenario for each measure has been selected.

Table 22. Comparative summary table (Reference primary energy is 161 kWh/m²/year)

Measure	Type	Heating improvement	Cooling improvement	Primary energy rating (kW/m²/year)
Insulation	Wall 0.01 m Gypsum plasterboard + Roof 0.1 m XPS	23%	5%	154 (compared to 161 for reference case)
Shading	Overhangs (for kitchen)	0%	8%	160
	Louvres (for circulation area)	-31%	43%	160
LoE windows	-	1%	1%	160
Desk lamps	-	38%	-24%	267
Lighting control	-	-10%	6%	135

As can be seen, applying lighting control would be the measure with the highest reduction of the primary energy rating, i.e., the measure that would maximise the energy savings on the building.

Suggestions for future work

This project has proven that there are effective measures to reduce electricity consumption in the building under study, but prior to implementation of the measures stated as feasible, an economic analysis of said measures should be carried out to assess whether they fit within the company's budget and then continue discarding measures until the most optimal ones are chosen.

Regarding the overall actual electricity consumption, it should be investigated why it reaches such a high value when compared to the modelled results. Factors such as excessive infiltration, leaving doors open, low efficiency of air conditioners, etc. should be further investigated

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