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MAXIMISING ENERGY EFFICIENCY THROUGH BUILDING RENOVATION

HSBC Case Study

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Foreword

The Malta Chamber of Commerce, Enterprise and Industry, in collaboration with the HSBC Malta Foundation, has been working together for the past three years on the project titled 'Maximising energy efficiency through building renovation: HSBC Case Study'. This initiative transcends mere architectural plans for net-zero office spaces; it stands as a testament to our shared responsibility in confronting one of the most urgent challenges of our era: climate change. With a primary focus on operational carbon within the building and construction sector, this project seamlessly aligns with Malta's dedication to fulfilling its climate objectives.

Drawing inspiration from HSBC's flagship building in Qormi, our emphasis on improving energy efficiency in office structures is deliberate, acknowledging their substantial contribution to carbon emissions. The reduction of these buildings' carbon footprint is not solely an environmental necessity but a pivotal step toward realising Malta's decarbonisation objectives and fostering enhanced ESG compliance among enterprises. The active involvement of key governmental bodies and ministries, along with professionals from various sectors, underscores the significance of a collaborative approach. We anticipate that our efforts will facilitate the seamless integration of sustainability principles into business models and future strategies.

Under the guidance of Ing. Abigail Cutajar, the technical aspect of the project illuminates the meticulous assessment of Malta's building inventory and the targeted selection of office buildings for energy modelling. The case study featuring the HSBC head office exemplifies our commitment to transforming existing structures into more efficient, sustainable offices.

We extend our sincere congratulations to all contributors to this visionary endeavour. The 'Maximising energy efficiency through building renovation: HSBC Case Study' project marks another significant milestone in our sustainability journey.

Chris Vassallo Cesareo
President
The Malta Chamber of Commerce, Enterprise & Industry

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CEO
HSBC Bank Malta

Executive Summary

Achieving Malta's climate targets necessitates a transformative shift in the building and construction sector towards sustainable living spaces. This study lays the groundwork for such a transition, paving the way for future ambitious studies, policies, and strategies.

Through this project, HSBC Malta Foundation asserts itself as a vanguard in net zero carbon research, charting unprecedented territory in Malta. This initiative not only spearheads groundbreaking efforts but also serves as a catalyst for shaping a comprehensive roadmap. By reframing the sector, it transcends mere economic contribution, becoming a force for enhancing livelihoods and safeguarding the environment. Malta, in alignment with its commitments to the European Union, faces a significant journey towards meeting its climate objectives. This initiative represents a bold and forward-thinking stride for the sector, leveraging green finance and prioritizing the well-being of its populace to harmonize economic development with environmental responsibility.

Central to this endeavour is the establishment of energy-efficient building standards, imperative for the transition towards a net zero carbon economy. The development of energy use intensity targets tailored to different building types emerges as an immediate priority within this study. The Malta Chamber of Commerce, Enterprise and Industry and its members assume a pivotal role in advocating for the net zero carbon framework, exerting influence on both public perception and governmental policies. This initiative pledges tangible progress towards climate targets, furnishing benchmarks for gauging success and enabling the execution of sustainable ventures.

Concrete and tangible commitment from the public and private sectors are imperative to cement these sectoral commitments to lead the green transition. This commitment is vital for driving the energy efficiency agenda within the broader context of climate change and energy policy. It is essential that organizations which are leading the pathway are truly acknowledged and awarded. The work being presented outlines a consistent pathway towards a net zero carbon-built environment, with The Malta Chamber of Commerce spearheading efforts to fortify its resilience and inclusivity. Collaborative engagement with stakeholders stands as a linchpin for success, ensuring transparency and periodic updates to sustain relevance and efficacy.

This study delineates a comprehensive framework of steadfast principles and metrics, poised to establish benchmarks integrated into policy frameworks. Primarily, it serves as a tool for both governmental bodies and businesses to catalyse the transition towards a net zero carbon-built environment.

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Introduction

This report presents the contributions of Work Packages 1 (WP 1) and 2 (WP 2) towards the project titled “Maximising Energy Efficiency through Building Renovation: HSBC Case Study”. Through the findings of this study, an overarching framework of principles have been outlined which can be integrated into policy and provide the tools for government and businesses to drive higher energy performance of buildings.

In this report, WP 1 involves **Research & Data Collection for the Framework** and WP 2 constitutes the **Data Management** and **Guidelines towards Maximising Energy Efficiency through Building Renovation: HSBC Case Study,** using the HSBC Headquarters in Qormi as the baseline building. The outcomes of this study will be explored throughout this report.

Label showcasing benefits of the project

Definition for Net Zero Carbon Buildings

HSBC Hub Offices

The project adopts the World Green Building Council's definition of a net zero carbon building, which states that it: "is a building whose total energy usage does not exceed the amount of renewable energy produced, and one which is highly energy efficient" [1].

The 'C40 Cities Climate Leadership Group'[2], which constitutes a group of 97 cities around the world, representing one twelfth of the world's population and one quarter of the global economy, describes net zero carbon buildings as "green and healthy buildings" that "use energy ultra-efficiently and are supplied by renewables" and which "are comfortable homes where money is not wasted on energy bills, productive workplaces insulated from extreme temperatures, and healthy schools free from dirty air" [2]

According to the World Green Building Council (2020)[3], a net zero carbon building generally adopts several approaches to carbon mitigation within the building including:

Net Zero Carbon through Construction

"When the amount of carbon emissions associated with a building's product and construction stages, up to practical completion is zero or negative, through the use of offsets or the net export of on-site renewable energy".

Net Zero Carbon through Operational Energy

"When the amount of carbon emissions associated with the building's operational energy on an annual basis is zero or negative. A net zero carbon building is highly energy efficient and powered from on-site and/or off-site renewable energy sources, with any remaining carbon balance offset".

Net Zero Carbon through the Whole Life Cycle

The definition utilised states that a building fulfils this criterion *"when the amount of carbon emissions associated with the whole life cycle of the building based on its total lifetime is zero or negative".*

Out of the three approaches, this project focuses mainly on the Operational Energy towards achieving a Net Zero Carbon Building. This is mostly related to the emissions of carbon dioxide (CO_2) and other global warming gases during the in-use operation of a building. Given that operational carbon, as opposed to embodied carbon, represents two-thirds to three-quarters of a building's life cycle impact in countries with mixed energy supplies [4], this was given the greatest level of commitment in this assessment.

WP 1: Research and Data Collection

Scope

The initial scope of this work package was to carry out the market research required to understand the local status of Net Zero Carbon Buildings which eventually resulted in evaluating High Energy Efficiency Buildings. Part of this process involved gathering the relevant data using desktop research. This was carried out while also acquiring sufficient background information from other case studies beyond Malta's shores.

Data acquisition from all relevant stakeholders, will be outlined hereunder, also provided a reference point in presenting the case for recommendations towards achieving highly efficient office spaces in Malta, and which in this project included a study which assessed a local office building.

This was followed by further groundwork to organise the data into a well-defined database of Malta's building stock. This database was constructed to include the relevant sections of the building stock. Following an in-depth discussion with the client, it was decided that the case study would be an office building. This type of building stock had to date not been assessed previously in Malta. For this reason, setting up recommendations for such typical building energy use were expected to result in a new untapped niche within our islands.

Carrying out structural works including core re-structuing

An evaluation of the existing baseline office buildings enabled the development of a methodology to organise the data and carry out the analysis required in the next phases of the project. This included defining the **Benchmark Method** and metrics used based on the data acquired, or in this case generated. A description of this process is explained hereunder.

The team reached out to several stakeholders, who are listed hereunder. The main objective was to obtain existing data for an in-depth study of the typical office buildings chosen as part of this study.

Meanwhile, through an in-depth discussion HSBC's main office building in Qormi was chosen for the case study as it was also earmarked to undergo a major renovation, and therefore could possibly be retrofitted. This was also expected to enable the quantification of operational energy savings, and the financial feasibility of implementing various energy conservation measures within the case study building. The results would be presented to the HSBC renovation team with the aim of optimising the energy-retrofit measures and their contribution towards achieving recommendations for highly efficient office spaces. Prior to assessing the case study building itself, the team carried out an assessment of the data acquired from the identified stakeholders. Multiple meetings were held to provide a thorough explanation of the project scope and acquire the correct data.

This phase also sought to focus on generating and promoting potential links for research and development within the building and construction sector in Malta. Through joint efforts with relevant stakeholders, the project team looked at establishing interrelations within the industry with the purpose of assisting all involved.

As mentioned, the project targets **commercial office buildings**, a decision that was taken based on the following criteria:

1. A high percentage of building stock is attributed to this type of building, and therefore, **data availability** for office spaces is greater in comparison to other types of buildings.
2. From a financial aspect, the commercial building stock is more likely to opt for green certification, and commercial office spaces **constitute the fastest rate of return on investment**.

The objectives of this work package were to:

- Develop the building stock database.
- Define the benchmark method and definition of metrics based on the data acquired.
- Define the data collection methodology.
- Acquire data from defined stakeholders, mainly Building and Construction Authority, Enemalta and Water Services Corporation.
- Evaluate the data collection.
- Collect and analyse a case study.
- Select the types of energy uses from Energy Performance Certificate (EPC) data valid for the net zero carbon framework.

Two main types of benchmark (ratings) are used to assess the current building stock; the asset and operational rating. Asset ratings are based on the simulated energy use of a building energy model characterised with default occupancy and equipment schedules, climate, and comfort set-points. On the other hand, operational ratings are based on measured energy use, often normalized for relevant variables like climate and level of energy service [5].

The local Nearly Zero Energy Benchmarks (NZEB) set in the 2015 Nearly-Zero Energy buildings plan for Malta [6] are based on an asset rating approach, in which the energy performance of the non-residential building stock uses the building energy modelling software, SBEM-MT [7]. The building physics energy models from the SBEM-MT software are stored as NCT files.

Ongoing works

Establishing operational energy performance benchmarks (operational rating) for a building stock requires a substantial building stock database that includes information on the operational energy consumption of individual buildings and the characterisation of these buildings in terms of form, equipment, operation, and envelope data. An important aspect when establishing such benchmarks is to ensure that the building observations in the database operate in compliance with EN 16798-1 [8]comfort and Indoor Air Quality (IAQ) set points. Buildings that are not compliant with these requirements are likely to have a lower energy consumption due to a lower energy demand but are not in line with the Energy Performance for Building Directive (EPBD) [9]that gives priority to optimise health, indoor air quality and comfort levels for the occupants in the buildings. Data collection efforts were initiated, however, after thoroughly exploring various options, a consultation with project stakeholders was held. The team established that due to the limited availability of operational energy consumption data, an extensive project on its own merit would be required when the legislative framework to allow this becomes available. To counteract this limitation in operational energy performance data, the project team focused on the asset rating energy performance of the local standards by analysing a sample of the Energy Performance Certificates (EPC) database for office buildings. At the time of project start data, there had not been any attempts to study the EPC database for office buildings. The analysis of the EPC database allows an evaluation of the current energy performance of the building stock in terms of energy use intensity (kWh/m^2/year). By analysing various combinations of energy efficiency measures on the building physics energy models, one is able to identify potential benchmarks for different building stock clusters.

The EPC database analysis was carried out through direct collaboration with the Building and Construction Agency (BCA), who provided a database in the form of a spreadsheet containing extracted data from the individual building physics energy model (NCT files). Unfortunately, the database did not include data for building characteristics parameters in terms of form, envelope, and equipment specifications for individual buildings as well as other important classifiers, including the age of the building.

Data that characterises the individual buildings in the stock such as building form, envelope, and equipment [10] is required for a comprehensive approach to cluster the building stock taking into consideration the most significant input parameters impacting individual building energy performance. The median observation for each cluster generally defines the typical building for each cluster and these buildings are termed 'Reference Buildings' [11]. These are used to study the energy performance of the entire building stock. The technical and economic analysis of combinations of energy conservation measures applied to the typical buildings' energy models allows policy makers to establish cost optimal and NZEB energy performance benchmarks for each building stock cluster. Once these benchmarks are derived, the energy savings potential of a typical building in the cluster can be aggregated from building level to cluster level and to the entire building stock to establish long term policies to decarbonise the building stock by 2050. A comprehensive review of establishing 'Reference Buildings' to study a building stock is found in Gatt et al. [12].

The comprehensive clustering analysis to define typical buildings, as detailed in Gatt et al. [12] and establish energy performance benchmarks, was not possible to comprehensively implement due to the limited data available in the EPC database provided by BCA. Only the total floor area and the building energy performance data were available. This building energy performance data includes the operational annual primary energy performance (kWh/m2/year) and annual operational carbon emissions data (kgCO2eq). Furthermore, the actual building physics energy models, specifically the NCT files, were not available to allow identified typical (Reference) buildings to be simulated with energy efficiency measures.

Stakeholders

The data required from the multiple stakeholders vary depending on the type of business use. In general, this relates to energy use, utility bills, and occupancy data. The data and source of information in relation to the existing building stock database, as well as the targets and Government's vision to decarbonise our building stock, was found to be dispersed across various agencies, government entities and stakeholders. It is important to mention that although the team has reached out to multiple stakeholders, there were times when it was challenging to acquire the requested data due to various limitations. The purpose for reaching out to stakeholders was to build an understanding of the local market, current building trends and reported builds, as well as the Government's vision for the public sector. The following stakeholders were approached and considered:

Private Stakeholders

HSBC Bank Malta p.l.c.

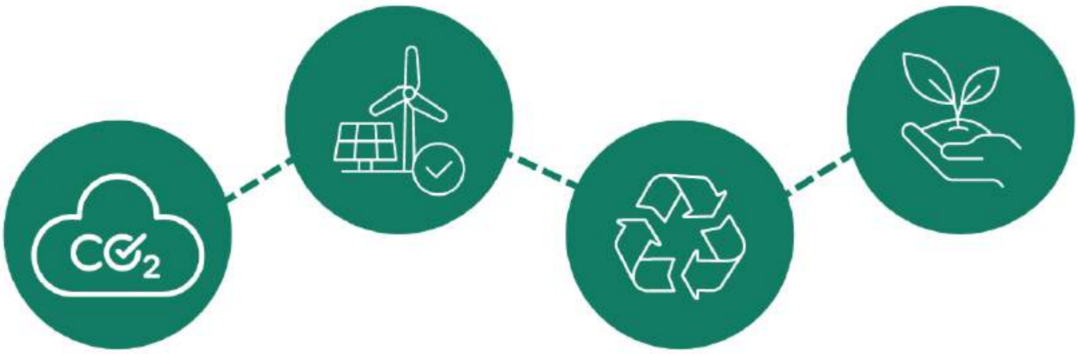
As the project envisaged to include an overview of sustainable financing mechanisms, the partnership with HSBC provided an opportunity for the financial institution to offer its expertise in the sector, ensuring that the project policy conclusions were aligned as appropriate. Also, the case study which is assessed in WP 2 requires significant information to model the existing main HSBC headquarters in Qormi. For this reason, meetings were carried out with various HSBC employees to acquire this data. The main outcomes were related to the baseline energy model carried out in WP 2 and the optimised building simulation to set up a typical net zero building where in this case the focus is on office buildings. The process involved a series of discussions with HSBC's Country Head of Corporate Services, the Building Relationship Manager, and the Facilities' Manager representing JLL, which is HSBC's contractor amongst others.

Governmental Stakeholders

The Ministry for Environment, Energy and Enterprise (MEEE)

One of the main reasons why the team decided to reach out to this Ministry (former Ministry for the Environment, Climate Change and Planning) was to understand the Government's vision for the target to decarbonise the economy by 2050. The building stock is the second highest carbon attributor to local emissions; therefore, this sector is high on the Government's decarbonisation agenda.

The Low Carbon Development Strategy (LCDS), National Energy and Climate Plans (NECPs) and Long-Term Renovation Strategy (LTRS) are all under the direct responsibility of MEEE. To ensure that the work conducted for this project aligns with the Government's vision to decarbonise the economy by 2050, and since the building stock plays a vital role in this shift, it was decided that the technical team would consult the Ministry to acquire technical insight on the three Strategies and Plans. A series of discussions were organised both with Civil Servants and high-level officials and Advisers from the Secretariat's end.



The Ministry's message was clear, the programme of measures for the building stock intensified as incentive schemes were launched with regards to the installation of energy efficiency measures such as solar water heaters and heat pumps as well as double glazing in residential buildings.

Further measures in line with the Government's commitment and ambition towards renovation include deep retrofitting of old houses and the installation of energy efficiency measures within the building industry. The Government continues to promote such efforts, and plans are underway to roll-out the renovation strategy programme under the Building and Construction Authority's responsibility.

Further discussions revolved around the commercial and industrial sectors where the need for their commitment towards climate neutrality goals was re-iterated alongside the government's continued support through energy efficiency schemes designed specifically for industries to switch to cleaner operational processes and energy-efficient space use. To date, schemes in relation to buildings are not generally supported under Malta Enterprise, however it is pertinent for the private sector to emphasise the need for this shift.

Water Services Corporation (WSC)

Since the WSC is responsible for the national water distribution and groundwater operations, this entity was contacted to extract water bills of selected offices. The team set up a technical meeting and a consent form was prepared by The Malta Chamber to circulate with its members, obtaining permission for WSC to be able to give us actual data for office spaces.

Enemalta p.l.c.

As the distributor and transmission system operator in Malta, this entity was contacted to ensure that, if necessary, the requested electricity bills of the selected offices could also be acquired. Enemalta's contribution to the project was to provide data on electricity supply, demand, and conservation to understand the difference between the actual and estimated data. A consent form, like that requested by WSC, was constructed to receive ARMS's energy bills covering three years, for indicated account numbers corresponding to several office buildings. The energy bills reflected actual data for typical office spaces and were used to compare with HSBC data for the baseline building in Qormi. Comparing these quantitative futures with the estimated optimised energy performance figures, to reach a high-performance energy office building.

Planning Authority (PA)

The team reached out to the Planning Authority to support the project by allowing use of their existing building inventory based on gross floor area and class of use. The data proved not to be relevant to the study and was therefore excluded.

Building and Construction Authority (BCA)

The Building and Construction Authority (BCA) proved to be a key partner in the work conducted throughout WP 1. Since the BCA is also responsible for spearheading the creation of a construction ecosystem, embracing good governance, policies and promoting compliant and sustainable buildings, it was a natural choice to request access to most of the data from this Authority. This Authority was of key interest to the project due to the data it possesses on energy performance of the Maltese building stock, such as the EPC database. The following section elaborates and explains the data requested and collected from this Authority.

The process of Building Stock Assessment to study the Energy Performance of the Office Building Stock

The EPC database provided by BCA provided energy performance and floor area data of 741 Energy Performance Certificates (EPCs), all of which pertained to office buildings. The database included information both for the asset (as built) and design rating systems. This data was vetted, and a detailed analysis was produced.

Given data limitations, such as the absence of data that characterises individual buildings in the database and the unavailability of the building physics energy models (NCT files), the approach in literature generally used to establish Reference Buildings, as explained in Gatt et al. [12], could not be implemented. In response, a new and innovative process was introduced to analyse the asset rating energy performance of offices building stock, considering the 741 EPCs (buildings) registered at the time of the analysis. This was therefore proposed and a potential framework for analysis of the local EPC building stock was established to help policy makers.

The innovative process aimed at defining typical buildings involved clustering directly on the energy performance and building floor area variables to identify typical buildings for analysis. This approach differed from the conventional method of clustering independent variables that characterise the building stock in terms of operation, form, envelope, and equipment, impacting operational energy performance, as explained in Gatt et al. [12]. Once the mean cluster observations that were deemed to define the typical buildings and their corresponding certificate number were identified, an analysis of the certificate number allowed one to extract further information on the form, envelope, and equipment characteristics of the typical buildings. This was achieved by inputting the certificate number on the BCA website [13], that allows such data to be extracted for each building separately both in spreadsheet and pdf format.

This characterisation can allow the identification of energy efficiency measures that can be applied on each identified typical building for the establishment of cost optimal and Nearly Zero Energy Benchmarks (NZEB) in line with the European commission [11]. However, performing such cost optimal analysis also requires simulating energy efficiency measures using the building physics energy models (NCT files) themselves for the typical buildings to quantify the potential energy savings for a package combination of energy efficiency measures.

It is important to note that to identify potential outliers or errors in the database, it is necessary to evaluate the characteristics of other observations near the median of the clusters that define typical buildings before establishing general characteristics for each typical building.

To explain in further detail, the EPC building analysis using this data was carried out as follows:

Acquisition of the office buildings database

The database of office buildings for which an EPC was issued was provided in CSV format by the BCA. In the CSV file, only the total floor area and the building energy performance data were extracted from the NCT files and available for assessment as detailed in the previous section.

Identification of variables available in the database

The following variables were considered for the analysis of the EPCs:

- Total building floor area
- Annual operational $C0_2$ emissions (kg/(m^2.yr))

- Annual operational (primary) Energy User Rating (kWh/(m^2.yr))
- Building asset rating, EPC band

During this process, the design ratings were eliminated due to uncertainties associated with the building energy model parameters of the building at design stage. The analysis focused only on asset-rating buildings. Figure 1, which describes and compares the annual operational CO_2 emissions (kg/m^2.yr) of the asset and design rating, reveals that the design rating has a larger variance. Further analysis, particularly if NCT files become available, could help attribute this variance to errors, uncertainties, or variations in parameter inputs.

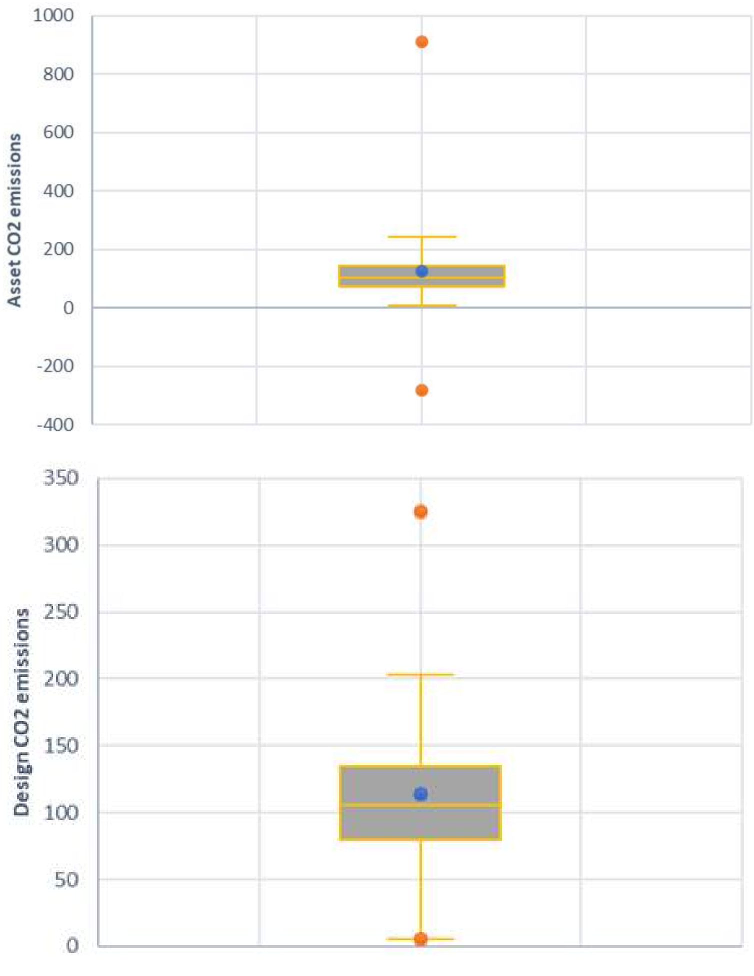


Figure 1: Boxplot comparing the asset (top figure) versus the design operational ratings (bottom figure) of the building stock

Cleaning of data by the removal of duplicate data from the database

Duplicate entries were removed from the database prior to analysing the data.

Descriptive statistics and correlation analysis between the variables

Descriptive Statistics

Table 1 presents a summary of descriptive statistics of the four variables for the office building stock under study. The corresponding boxplots of the variables are also depicted in Figure 2 to Figure 5. As depicted in Figure 2 and Figure 3, there are only 3 building observations that can in theory be defined as a positive energy building with a negative primary energy rating. This is attributed to Photovoltaics generating more energy than is consumed by the buildings. Most of the operational primary CO_2 emissions and primary energy consumption lie between 75 and 143 kg.m^2.yr^{-1} and 294 and 560 kWh/m^2.yr^{-1} respectively based on the 1st and 3rd interquartile range. Furthermore, most of the building floor areas lie between 60 and 562 m^2, but the data for floor area is also highly dispersed with a minimum floor area of 10 m^2 up to 18,774 m^2. The 10 m^2 observation entry seems erroneous and needs further review when the NCT files are available.

Table 1: Descriptive Summary Statistics for the four variables under study

Statistic	$C0_2$ Emissions (kg/m^2.yr)	Energy User Rating (kWh/m^2.yr)	Floor Area (m^2)	Building Asset Rating
Number of observations	578	578	578	578
Minimum	-281	-1,104	10	-715
Maximum	910	3,578	18,774	821
1st Quartile	75	294	60	110
Median	103	403	136	133
3rd Quartile	142	559	562	161
Mean	123	486	705	146
Variance (n-1)	9,892	157,717	2,780,591	8,814
Standard deviation (n-1)	99	397	1,668	94

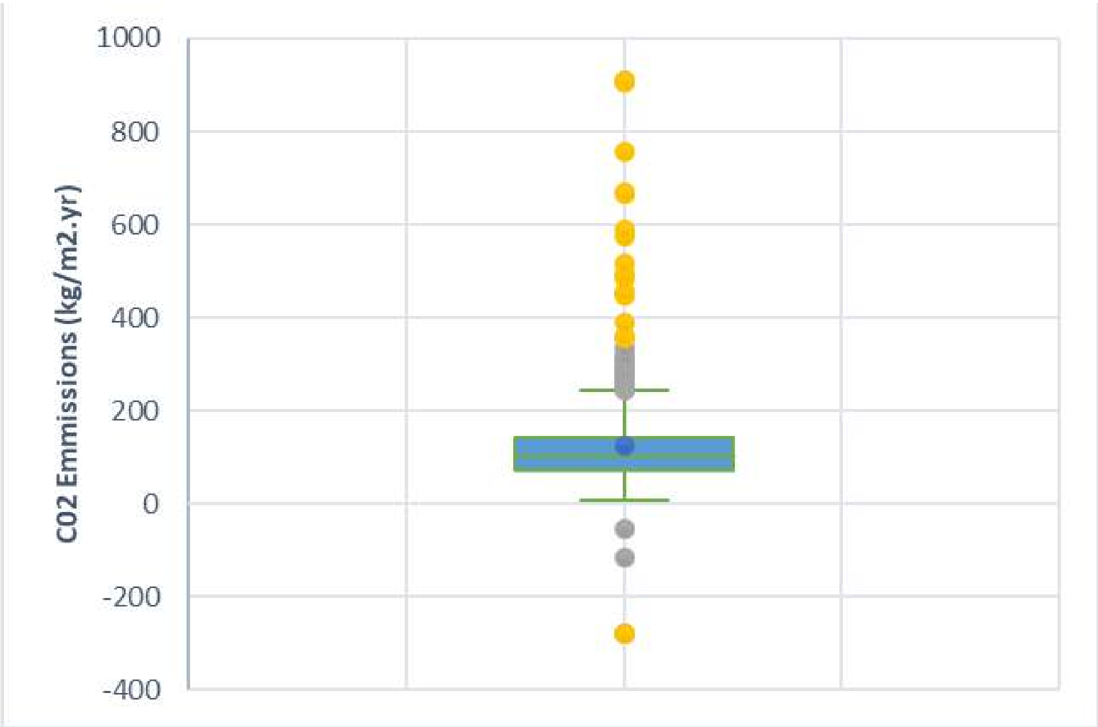


Figure 2: Boxplot depicting the operational kg CO2 emissions dispersion of the building stock

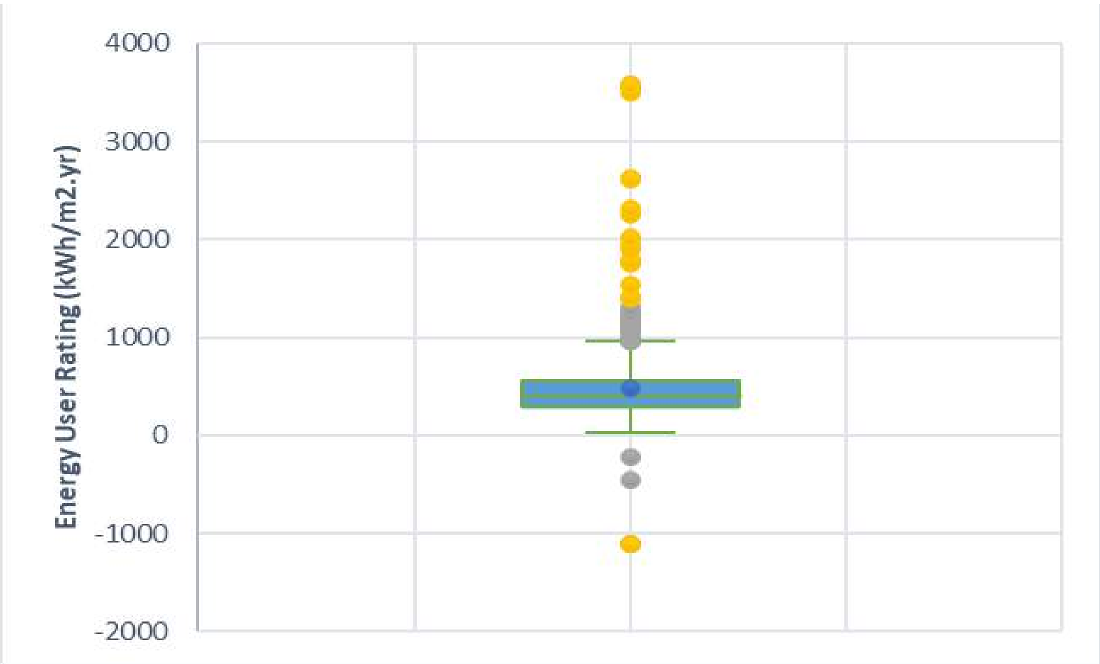


Figure 3: Boxplot depicting the operational primary energy consumption of the building stock

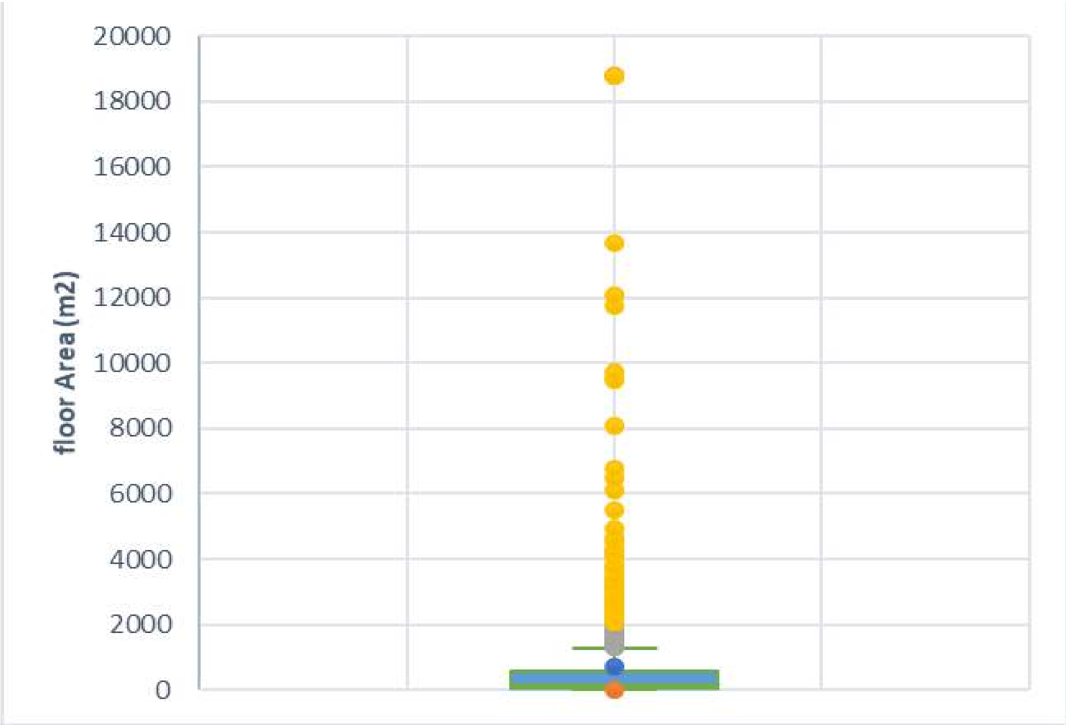


Figure 4: Boxplot depicting the floor area (m²) of the building stock.

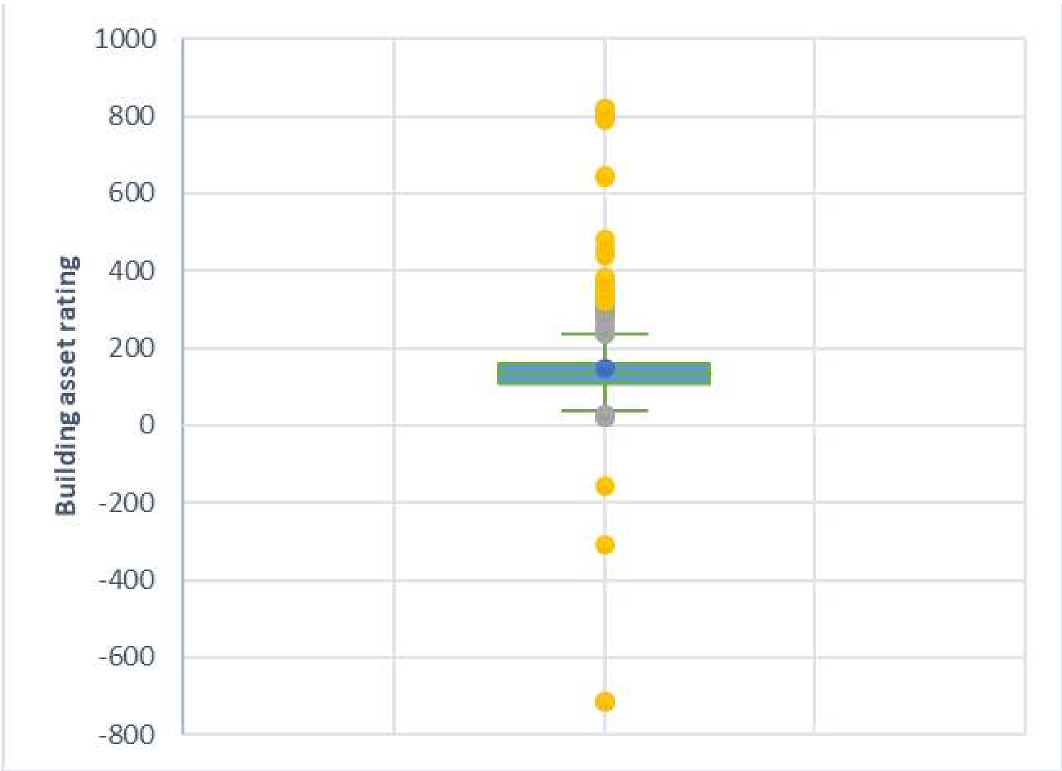


Figure 5: Boxplot depicting the Building Asset Rating of the building stock

The Building Asset Rating value used to determine the building EPC band (A+ to G), was computed following the SBEM-mt technical manual. This manual compares the building under study to a building of similar geometry, with its envelope and equipment properties compliant with the minimum requirements, plus an improvement factor of 20%. The number and percentage of building observations that fell under each EPC band are depicted in Figure 6 and Figure 7 These figures show that more than 50 % of the building stock fall in band B and C, while over 30 % of the buildings fall in band B and D or lower. Thus, given that most buildings did not fall in bands A and B, there is a good potential to improve the energy performance of the office building stock.

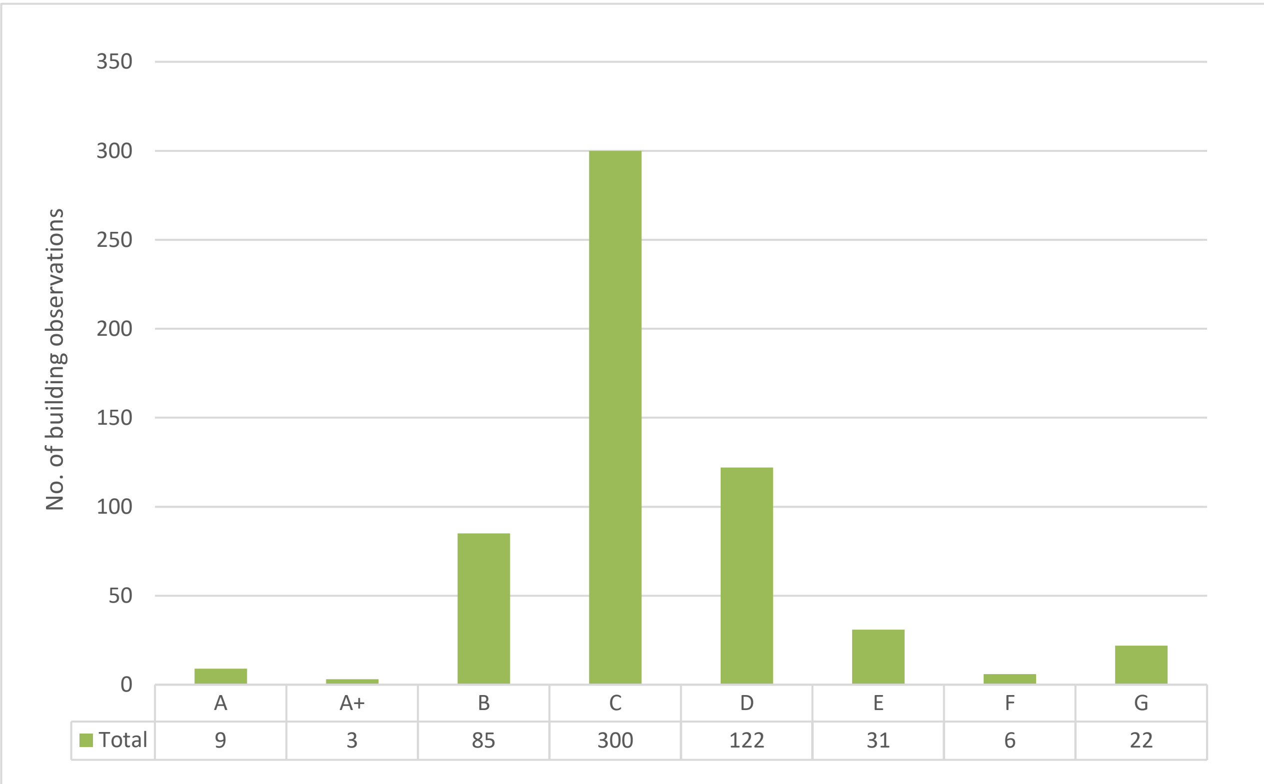


Figure 6: Graph showing the number of observations per EPC band.

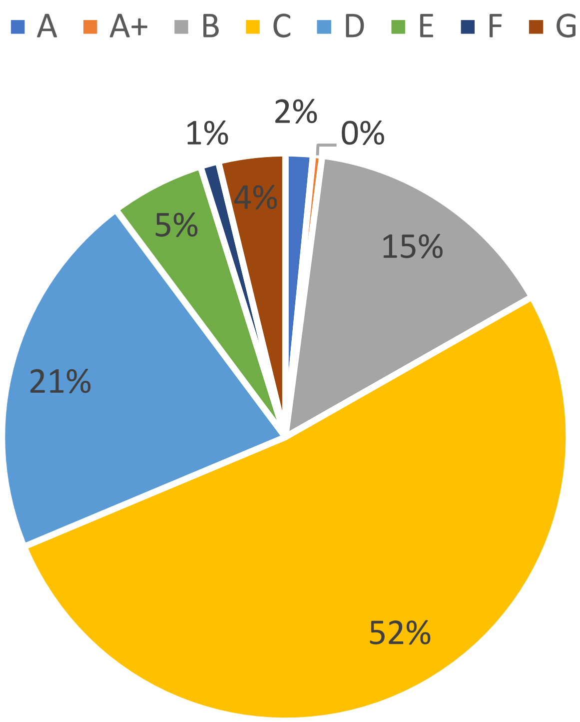


Figure 7: The % percentage number of observations per EPC band

Correlation analysis

Table 2 and Table 3 depict the Pearson correlation analysis between the four variables under study. From the results displayed in these tables, the annual operational $C0_2$ Emissions (kg/m^2/year) were highly and significantly correlated with the annual operational energy user rating (kWh/m^2/year) (r=1). Both these variables however had a weak correlation with the building floor area (r<0.1). Thus, given the high correlation between annual operational CO_2 emissions (kgCO_2eq/m^2/year) and annual operational Energy User Rating (kWh/m^2/year), both variables could not be considered together for clustering analysis given multi-collinearity issues. Therefore, the annual operational primary energy user rating (kWh/m^2/year) was retained in line with the EPBD cost-optimal guidelines. The correlation between the Building Asset Rating, which determines the EPC band, and operational primary energy user rating and annual operational CO_2 Emissions (kgCO_2eq/m^2/year) was also strong (r=0.7). However, for this analysis, which aimed to understand and identify the potential for improving the operational energy performance of the building stock, the EPC band was not a factor of primary importance in the analysis when compared to the annual operational CO_2 Emissions (kgCO_2eq/m^2/year) and annual operational Energy User Rating (kWh/m^2/year).

Table 2: Correlation Matrix (Pearson)

Variables	CO_2 Emissions (kg/m^2.yr)	Energy User Rating (kWh/m^2.yr)	Floor Area (m^2)	Building Asset Rating
CO2 Emissions (kg/m^2.yr)	**1**	**0.999**	**-0.080**	**0.706**
Energy User Rating (kWh/m^2.yr)	**0.999**	**1**	**-0.080**	**0.693**
Floor Area (m^2)	**-0.080**	**-0.080**	**1**	-0.051
Building Asset Rating	**0.706**	**0.693**	-0.051	**1**
Values in bold are different from 0 with a significance level alpha=0.05				

Table 3: Coefficients of determination (Pearson)

Variables	CO2 Emissions (kg/m2.yr)	Energy User Rating (kWh/m2.yr)	Floor Area (m^2)	Building Asset Rating
CO2 Emissions (kg/m^2.yr)	**1**	0.997	0.006	0.499
Energy User Rating (kWh/m^2.yr)	0.997	**1**	0.006	0.481
Floor Area (m^2)	0.006	0.006	**1**	0.003
Building Asset Rating	0.499	0.481	0.003	**1**

Clustering analysis

Hierarchical clustering, using the Ward method, was performed using the annual operational Energy User Rating (kWh/m^2/year) and building floor area variables. The floor area was deemed an important variable to consider as it gives weighting to the size of the building when establishing typical buildings for analysis. From the resulting hierarchical dendrogram, an optimal number of five clusters resulted, taken to maximise the dissimilarity between the clusters as can be seen in Figure 8. Cluster 5 was eliminated for the analysis, as only one building observation fell within the cluster as identified in Table 5. Table 4 shows the cluster centroids while Table 5 shows the descriptive statistics for the clustering solution chosen.

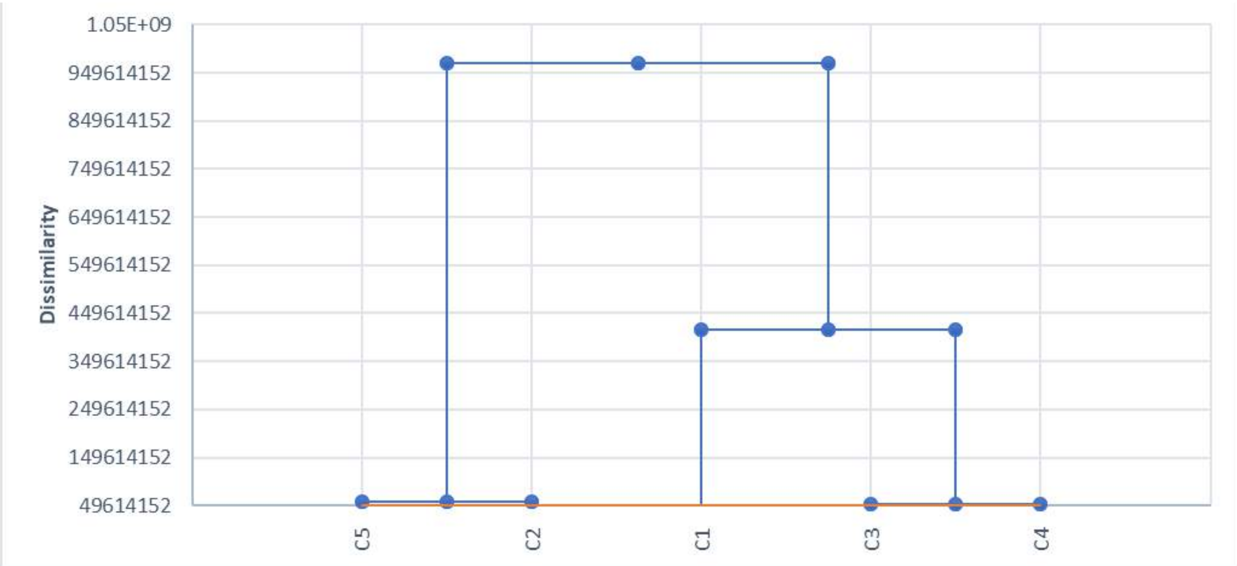


Figure 8: Dendrogram illustrating the dissimilarity between the five clusters

Table 4: Cluster centroids

Class	Energy User Rating (kWh/m^2. year)	Floor Area (m^2)
1	428.448	3271.90
2	424.750	10612
3	337.735	783.14
4	549.769	102.01
5	89.740	18774.0

Table 5 : Observations per cluster and descriptive statistics for each cluster

Class	1	2	3	4	5
Objects	51	7	139	380	1
Sum of weights	51	7	139	380	1
Within-class variance	1556006	4276689	180439	193943	0
Minimum distance to centroid	135	864	4.6	9.8	0
Average distance to centroid	1008	1733	361	272	0
Maximum distance to centroid	3488	3163	1465	3029	0

Identification of the Typical Office Building

As detailed above, the building observations closest to the centroid of the clusters provided the typical (median) buildings in terms of energy performance and floor areas. However, a building giving a median typical operational energy performance does not provide a guarantee that its equipment and envelope characteristics are also typical of the cluster. Therefore, analysing one building corresponding to the median of the cluster is not sufficient. To establish common, or average, trends in the building envelope and equipment parameters characterising a given cluster, a sample of the building stock near the median of each cluster needs to be carefully analysed. This process is required to establish a typical building or a building archetype for each cluster, upon which energy conservation measures can be applied. This is a time-consuming process given the lack of information characterising the existing EPC database and potential errors in input data.

As a preliminary evaluation, the observations in Table 6 below were identified as typical buildings, by observing two buildings near the median of each cluster. The cluster number that each building represents is also shown. The buildings are characterised in terms of:

- Geometry
- Envelope/Fabric
- Equipment

The characterisation was performed by downloading the pdf files corresponding to each observation using the BCA website [13].

Table 6: Eight (8) Typical Office buildings that were selected through a clustering analysis

Certificate Reference*		**1/2014**	**2/2015**	**3/2015**	**4/2016**	**5/2017**	**6/2017**	**7/2018**
Cluster Class		1	2	1	3	3	2	4
Ground Floor Area (m^2)		3,311	9,487	3,267	787	737	9,748	102
C02 Emissions ($kg/m^2.yr$)		76.18	49.46	62.67	86.58	89.11	102.94	142.4
Energy User Rating ($kWh/m^2.yr$)		299.34	194.36	246.24	340.2	350.15	404.49	559.54
Floor Area (m^2)		3,311	9,487	3,267	787	737	9,748	102
Building Asset Rating		99	85	84	27	130	116	176
EPC Band		B	B	B	A	C	C	D
Energy displaced using RES ($kgCO_2/m^2$)		0	0	2	0	0	0	0
Ventilation System		Mechanical – by HVAC System	Mechanical/Natural	Mechanical/Natural	Mechanical/Natural	Natural	Mechanical/Natural	Natural
Cooling System		Split/Multi Split System	VRF System	Split/Multi Split System	Split/Multi Split System	Split/Multi Split System	VRF with plate heat exchanger	Split/Multi Split System
Heating System		Split/Multi Split System	VRF System	Split/Multi Split System	Split/Multi Split System	Split/Multi Split System	VRF with plate heat exchanger	Split/Multi Split System
Cooling Seasonal Energy Efficiency Ratio	*(Most optimum)*	3.79	4	3.75	5.8	2	3	3
Heating Seasonal Energy Efficiency Ratio	*(Most optimum)*	4.11	4	4	6.1	2	3.5	3.2
Heat Recovery		No Heat Recovery	Plate Heat Exchanger Recovery System (HRSE -0.65)	No Heat Recovery	No Heat Recovery	No Heat Recovery	No Heat Recovery	No Heat Recovery
Type of Lighting		T8	T5	T5	T5	T5	Compact Fluorescent	Compact Fluorescent + LEDs
Heat Pump		Air Source	Air Source	Air Source	Air Source	Air Source	Air Source	Air Source
HWS		Stand Alone Heater	Stand Alone Water Heater	Stand Alone Water Heater	Stand Alone Water Heater	Stand Alone Water Heater	Stand Alone Heater	Stand Alone Heater

**Random certificate reference due to data protection.*

Summary and Way Forward

The clustering exercise detailed above, the results of which are shown above, does not reliably establish typical buildings in terms of building envelope and equipment characteristics for the purpose of this study. The reason for this being that potentially many combinations of envelope and equipment parameters can yield the same energy performance. To develop a dataset of the actual envelope and equipment characteristics that satisfies the requirements for clustering necessitates extensive data collection of actual envelope and equipment characteristics. This process requires one to download and analyse PDF files corresponding to the EPC certificate number of a good sample of buildings near the median of each of the four clusters developed above. Manual collection of information on the envelope and equipment parameters for each individual building is then required.

This process is both time-consuming and requires advanced statistical analysis to develop typical buildings. Furthermore, the building physics energy models (NCT files) themselves for the typical buildings need to be made available to study and quantify savings from energy efficiency measures. Given these limitations, it was decided that it was currently not practical to perform further analysis on the EPC database. Nevertheless, a proposed methodological framework to help policy makers study the EPC database is outlined in the following paragraph.

Bubbledeck structure

The proposed methodology of studying the database once these limitations are tackled can be put forward:

If only the variables described in the current database remain available, a clustering approach, like the one above can be undertaken. This process might benefit from employing more robust statistical techniques, such as linear regression and box plots, to eliminate outliers in building observations before clustering. Additionally, there is potential for extending clustering to include design-rated buildings, pending further validation of the data.

Download and analyse PDF files corresponding to the EPC certificate number of a good sample of observations, potentially 20 to 30 buildings (but using an iterative approach), near the median of each of the resulting clusters. Extract manually or through a Python program, information on the envelope and equipment parameters for each individual building, and construct a data frame for each cluster.

Perform statistical and machine learning techniques such as sensitivity analysis and clustering to identify the typical buildings from each data frame.

Obtain NCT files for the identified typical buildings.

Establish energy performance improvements opportunities from each typical building by identifying energy efficiency measures. Energy efficiency measures to be considered constitute passive measures such as insulation on walls and roof, active measures such as replacement of boilers with heat-pumps and more efficient HVAC systems, and renewable energy measures such as photovoltaics.

Simulate the energy performance improvement for each typical building considering a package of combinations of the identified energy efficiency measures. Establish cost-optimal and NZEB benchmarks using the approach detailed in the 2018 cost-optimal studies for Malta [14]or refer to the HSBC case study detailed in this report that considers global life-cycle costs.

Aggregate the potential energy performance improvements from the typical building observation(s) level to cluster level and the whole building stock in the EPC database, using variables such as floor area. In simpler terms, the resulting benchmarks in kWh/m^2/annum for each typical building representing a cluster of buildings can be multiplied by total floor of each cluster. This approach can approximate the potential energy performance improvements for the whole cluster and ultimately for the whole EPC database observations if the exercise is performed for each cluster. Such quantification of energy performance improvements allows one to better identify a robust, long-term renovation strategy for Malta to achieve its 2050 decarbonisation goals.

Review of Literature & Market Research

Introduction

This section of the report reviews the literature with respect to the sustainability of buildings and urban space. This study refers to the building and urban scale in addressing sustainability assessment, in the context of the HSBC project. Further, the report refers to indicators to help define the sustainability framework for the intended application, which however are contextualised to the Mediterranean and local case and validated with respect to case studies. Such a framework with indicators and Key Performance Indicators (KPIs) informs the sustainability assessment method adopted.

Objective

The objective is to analyse methods and tools that are used for the assessment of buildings and urban spaces/neighbourhoods (cluster of buildings and surrounding spaces), review the indicators used and their relevance in the Mediterranean context, and to assess case study applications and the outcome of such assessments. This can be applied to new buildings and retrofit applications.

Method

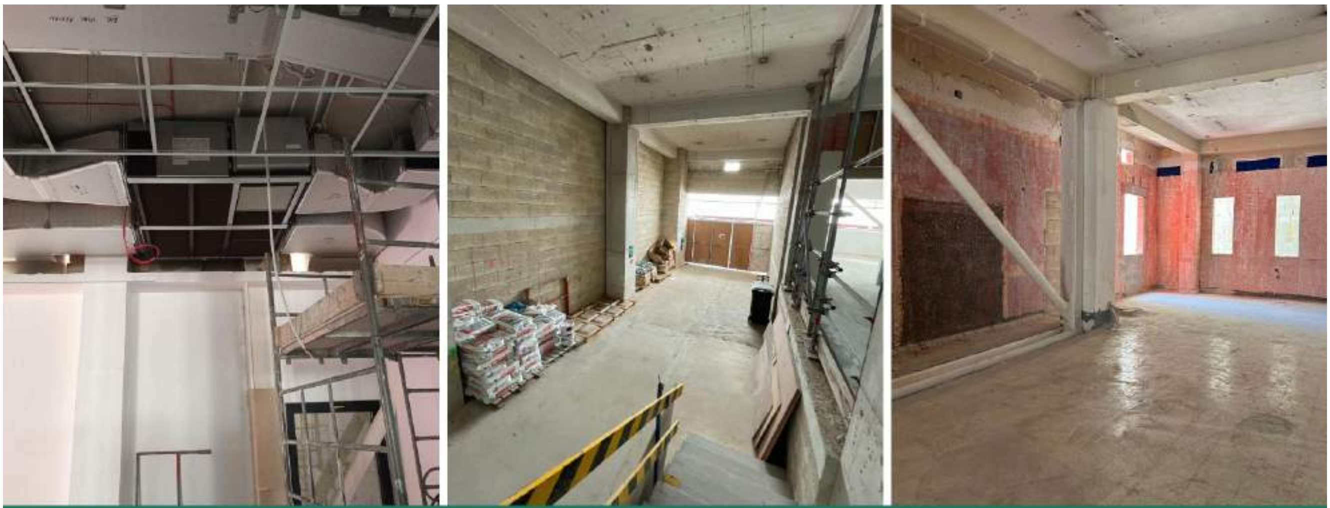
This section of the report refers to the following main sections:

(i) Background to Buildings and Sustainability to set the scene including reference to building assessment and urban area assessment and reference methods;
(ii) Sustainability Assessment Tools with reference to (1) HEART Contextualised building assessment tool and its critical assessment in Malta [15]; and (2) a review of existing sustainability assessment methods and indicators for buildings and urban areas)
(iii) Application of the CESBA Tool on example projects: case studies in the mediterranean region – building and urban scale [16], [17], [18], [19], [20].

To address these objectives, the Annex is structured as follows:

- A background on sustainability, energy efficiency, European frameworks, and rating tools.

- An assessment of existing sustainability assessment tools at building and urban scale.
- The assessment of a representative framework which is used to define issues and indicators of relevance in a Mediterranean context (CESBA) [17].
- The application of such tools through case studies in different Mediterranean regions to define urban and building assessment and the validation of such indicators (CESBA) [17].
- The review of KPIs and their applicability, in a local context (based on case study analysis) .
- The review of the application of the assessment at building and urban scale to wider case study examples which showcase best practice.



Ongoing works

Section Structure and Content

Reference is made to the full literature review and market research report presented as Annex to this report which focuses on the following key areas:

- Background on sustainability in the built environment.
- The context of the energy performance of buildings including gaps in the Maltese scenario.
- Sustainability assessment based on KPIs, with a focus on a Mediterranean context.
- Review of tools for sustainability assessment.
- Examples in sustainability assessment building and urban scale.
- Best practice examples where a neighbourhood award was launched, based on the sustainability assessment through KPIs. This report draws directly from this activity.

This section of the report also draws directly from, and refers directly to, documents prepared by the author and partners in the CESBA Med Project (Sustainable Mediterranean Cities – Interreg Med Programme of the European Union) [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32], including the University of Malta (UM) as key partner, and led at UM by one of the authors of the present report (RPB). The examples refer to the Mediterranean region and are therefore, in great part contextual and relevant to the local Mediterranean context of Malta. Other examples (including examples in Austria) are also presented in view of their relevance.

This review leads to the identification of key issues, gaps, and opportunities which may be exploited in a local context when referring to the sustainability of new build and retrofit of buildings and clusters of buildings/urban areas.

Background: Buildings and Sustainability

The European buildings sector represents 41.7% of the total annual final energy in the European Union Member States (EU-28) or 442 million tonnes of oil equivalent (Mtoe) in 2017 (Figure 9) and is responsible for ~30% of the total carbon dioxide emissions [33]. During their life cycle, buildings also use half of all raw material extraction and a third of all water consumption [34] . Furthermore, the waste stream from the construction of buildings and civil infrastructure, demolition, road planning and maintenance (i.e., construction and demolition waste—CDW) is one of the heaviest and most voluminous waste streams accounting for 25% to 30% of all waste generated in the EU-28[35] .[1]

[1] The background section draws also on detailed literature analysis conducted within the framework of the CESBA Med Sustainable Mediterranean Cities Research Project) (Ref. Balaras et al 2019 [36], Borg R.P. et al [37], 2019 & CESBA Med project – U.Malta 2019 [38]))

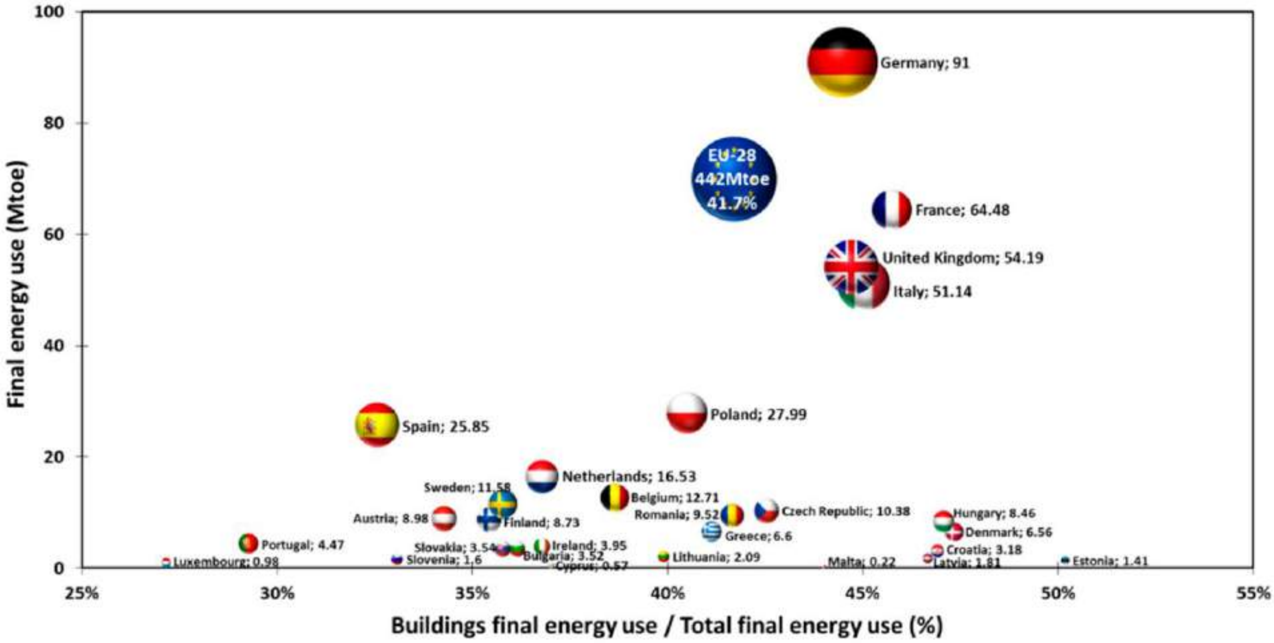


Figure 9 : *Final energy use (million tonnes of oil equivalent—Mtoe) in European buildings and ratio (%) of the buildings' final energy consumption to the total. The bubble size represents the total final energy use in each country; for EU-28, the value is not to scale. Data source: Eurostat* (Ref. Balaras et al 2019 [36], Borg R.P. et al [37], 2019 & CESBA Med project – U.Malta 2019 [38])) [36][38]

According to the European Commission's urban development network, the European urban areas are home to over two-thirds of the EU's population and account for about 80% of the final energy use. These urban areas are the engines of the European economy, but they are also places where persistent problems, such as unemployment, segregation, and poverty, are most evident. Urban development is central to the EU's Regional Policy, which addresses the environmental, economic, social, and cultural dimensions. An integrated approach is necessary to achieve sustainable urban renewals or new developments by incorporating environmental protection, education, economic development, social inclusion through strong partnerships between local citizens, civil society, industry, and various levels of government.

Recognizing the importance of buildings and the built environment, the Circular Economy Action Plan [39] initiated the EU's ambitious efforts to minimize the use of energy and natural resources in buildings, with radical resource efficiency and circular material flows as measures aimed at alleviating their environmental impacts. The 2030 EU climate and energy framework includes binding targets and policy objectives for reducing the greenhouse gas (GHG) emissions by at least 40% from 1990 levels, increasing the share of renewables by at least 32% of final energy consumption, and for improving energy efficiency by at least 32.5% [40]. Member States are also obliged to adopt integrated National

Climate and Energy Plans (NECPs) for the period 2021–2030 and develop national long-term strategies to ensure consistency with NECPs. One of the main instruments for addressing these challenges and the energy use in buildings is the Energy Performance of Buildings Directive (EPBD), recently amended by EU 2018/844 [9]that entered into force on 9 July 2018, an integral part of the “Clean Energy for All Europeans” package [41] .

EPBD

EPBD [42]promotes energy efficiency and cost-effective building renovations aiming to achieve a decarbonised building stock by 2050. The transition towards nearly-zero-energy buildings (nZEB) required focused attention on the renovation of national building stocks. These large-scale efforts could best be served by addressing groups of buildings in urban neighbourhoods. By considering synergies and energy interactions between individual buildings and the broader energy system at local level, the concept of zero-energy districts could be realised [43]. While the transition towards energy and spatial planning poses challenges, there are emerging best practices that encourage bottom-up initiatives. These practices emphasise neighbourhood-scale urban projects that utilise decentralised energy systems, local energy communities, energy districts and, and similar approaches [44].

Finalising the furnishings

Sustainable Development Goals (SDGs)

The European Union (EU) has played a crucial role in shaping the Global 2030 Agenda and United Nations Sustainable Development Goals (SDGs), integrating them into its policies and priorities [45]. SDG 11, focusing on sustainable cities, is central to addressing the built environment, with goals related to urbanization, transport, climate change, disaster resilience, and environmental impact reduction. The EU's Urban Agenda, launched in 2016, fosters collaboration to stimulate growth and address social challenges in European cities.

The recent SDG index for European cities indicates that no capital or large metropolitan area has fully achieved the SDGs, revealing significant challenges. Cities in Europe perform well on SDGs related to health, clean water, economic growth, and innovation but face challenges in responsible consumption, climate action, and biodiversity.

Cities' involvement is crucial for achieving the SDGs, addressing issues such as unsustainable consumption, climate change, poverty, and unemployment. European cities excel in health, clean water, economic growth, and innovation but struggle with responsible consumption, climate action, and biodiversity. The complexity of sustainable development efforts at the local level requires a bottom-up approach, emphasizing the importance of local actions in achieving global goals.
However, the development, monitoring, and assessment of local plans for sustainable development are complex and overwhelming for authorities lacking expertise and personnel. There is a need to support local authorities in accelerating progress, emphasizing the importance of a bottom-up approach in achieving global sustainability goals [45].

Existing Systems for Rating and Labelling

To systematically analyse and identify, quantify, and report opportunities for improved performance, energy and environmental audits have been conducted in industry, tourism, and the buildings sector. These audits collect crucial data that is essential for this analysis. Different schemes for building energy audits exist, depending on factors such as project intent, procedure (e.g., energy performance assessment, rating, certification, or labelling), operating conditions, and building type [46], [47].

The use of the term “energy audit” can be subjective and can vary from country to country since they are conducted in varying degrees or levels of technical detail, accuracy and complexity based on the purpose they serve. In some cases, this is done intentionally to reflect certain attributes, levels of complexity or stand-out in the market as a tailored process to a specific scheme and thus differentiate from other competing processes. Sometimes it may also be an unintentional result to directly link required processes to different legal acts and relevant regulations that may apply. Some examples include survey, screening, diagnosis, inspection, review, preliminary (detailed) audit or preliminary (detailed) assessment, or as it relates to financial assessments like an investment-grade audit or feasibility study.

In certain cases, intentionally using varying degrees of technical detail and complexity in energy audits serves the purpose of highlighting specific attributes and differentiating from competing processes to stand out in the market. On the other hand, unintentional variations may arise from efforts to directly align with specific legal acts and regulations. This can result in different terms such as survey, screening, diagnosis, inspection, review, preliminary (detailed) audit, or preliminary (detailed) assessment. Financial assessments, such as investment-grade audits or feasibility studies, also fall under this umbrella.

Practically all schemes include some common stages: preliminary contact (e.g., client interview to define project intent and collect preliminary information), intake (e.g., collect available data such as drawings, energy bills or metered data, perform an on-site visit, collect field data, complete checklists, audit forms and protocols, verify estimates and default values, perform in-situ measurements), analysis (e.g., rating, benchmarking, perform calculations or simulations, definition of a baseline to investigate energy conservation measures and assess scenarios, determine a list of cost-effective recommendations with quantified savings), and results (e.g., meet and present results to the client, generate reports and other deliverables).

Some schemes may have distinct characteristics (e.g., use specific calculation tools that will determine the input data, or deliver distinct results like an energy performance certificate or prepare documents and specifications for tenders). Sustainability audits in an urban context are more complex as they encompass a multitude of issues and themes that must be addressed [47].

Sustainability is also being adopted into building codes at different levels of government and with varying motivations. The approach taken reflects local societal perceptions, political priorities, national policies, and economic factors [48]. The creation of standards or codes that define a level of performance for sustainable buildings has emerged as a need within the industry. However, there are different approaches due to wide variations in economic, social, political, and technological conditions and priorities in different countries and jurisdictions around the world. Rating systems provide a method that one can voluntarily adopt and comply with various sustainability measures that meet a pre-defined set of requirements. Standards are also being developed as a collection of criteria for meeting the acceptable requirements at a high level of performance. They may be adopted in building codes or simply used as a level of performance that a project may comply by. For example, the ASHRAE Standard 189.1 that is recognized as a leading green standard around the world and forms the technical basis for the International Green Construction Code (IgCC), includes mandatory criteria in several sustainability issues and themes, site, construction, materials, energy, indoor environmental quality, and water and so on [49].

Finalising the furnishings

Building Scale Assessment

At building scale, various voluntary sustainability rating systems and labelling schemes have been developed to facilitate the process of reducing energy use and environmental impacts during construction, management, and operational phases [50]including:

- BREEAM [51], [52]
- CASBEE [52]
- Green Star [53]

- LEED [54]
- Protocollo ITACA [55]

The systems include different performance indicators that are used as metrics with fixed weighting and scoring systems to determine how well the sustainability objectives are achieved, facilitate the decision-making process, assess specific project requirements, or ensure compliance with regulations and norms [56], [57], [58]. The indicators serve as a measurement for desired outcomes, and depending on the specific project requirements and priorities, multiple indicators may be used at different stages. These indicators can be expressed numerically, such as a building's energy use intensity for performance assessment or comparison with benchmarks, or as rations and percentages, such as the proportion of renewable energy meeting power or heat demand, or the percentage of waste being recycled.

LEVEL(s)

The European Commission is developing a voluntary reference framework called LEVEL(s) [59], [60]to establish a common set of indicators for measuring the sustainability performance of buildings throughout their entire life cycle. This framework focuses on indicators related to greenhouse gas emissions, resource efficiency, water use, health and comfort, resilience, adaptation to climate change, cost, and value. The indicators are designed to link the specific characteristics of buildings (currently limited to residential and office buildings) to sustainability priorities. Users can utilise the framework to consider essential concepts and building-scale indicators, following specific guidelines and standardised calculations for each indicator.

The European platform Level(s) [51], [59]provides a common language for assessing and reporting on the sustainability performance of buildings. It is a simple entry point for applying circular economy principles in our built environment. Level(s) offers an extensively tested system for measuring and supporting improvements, from design to end of life. It can be applied to residential buildings or offices. Level(s) uses core sustainability indicators to measure carbon, materials, water, health, comfort, and climate change impacts throughout a building's full life cycle. It provides a solution for identifying sustainability hotspots and for future-proofing a project or portfolio, while contributing to EU policy goals to strengthen the sustainability of Europe's buildings.

Urban Scale Assessment

Several systems have also been extended to urban scale, e.g., BREEAM Communities, CASBEE for Urban Development [54], [61], LEED for Neighbourhoods and Protocollo ITACA Urban Scale [55]. The main aspects for sustainable cities address similar performance indicators like the ones for building scale, and include more categories, for example, urban transport, supply and distribution networks, social factors, etc. [Martos, 2016].

CESBA Med: The Common European Sustainable Built Environment Assessment for Mediterranean Cities [19]

A new European multicriteria assessment method has been developed that enhances existing knowhow in a holistic system for assessing urban sustainability of the built environment at neighbourhood scale. This complements the existing public approaches at building and city scales, so that it is more suitable and manageable to handle by municipalities.

This report outlines the main structure of the method and tools used for addressing the sustainability issues for buildings and urban neighbourhoods. A generic framework is presented with an emphasis on the energy and environmental indicators, together with the key performance indicators, presentation of results from nine European pilots through the provision of details for their application in Greece, as well as the training systems, including educational materials, developed, and managed by the University of Malta, for decision making and technical professionals.[17], [19]

Published Sustainability Assessment Projects and Methods

Sustainability Assessment Methods

This report refers to and reviews different assessment methods and projects which have been developed and which are outlined below. The available sets of indicators across countries and regions intended for the assessment of the sustainability of buildings and urban areas, which have been developed within the frame of the different international and trans-national projects and the public assessment systems, are analysed. A comprehensive overview of the available indicators and methods is presented and used to derive a generic list of indicators based on the level of relevance, operability, and affordability of the available indicators, for a Mediterranean context. This approach is applied for the development of the CESBA Med Framework for the Assessment of Buildings and Urban Areas.

Transnational Projects

- CABEE - Capitalizing Alpine Building Evaluation Experiences (ASP ALPINE Space Programme, European Territorial Cooperation, 2013-15) [52]
- CAT MED - Platform for Sustainable Urban Models (Interreg MED,2013-15) [62]
- CEC5 - Demonstration of Energy Efficiency and utilization of renewable energy sources trough public buildings (Interreg Central Europe, 2010-12) [63]
- CLUE - Climatic Neutral Urban Districts in Europe (Interreg IVC, 2011-14) [64]
- ENERBUILD - Energy Efficiency and Renewable Energies in the Building sector (ASP ALPINE Space Programme, European Territorial Cooperation, 2010-12) [65]
- EPISCOPE - Energy Performance Indicator Tracking Schemes for the Continuous Optimisation of Refurbishment Processes in European Housing Stocks (IEE, 2012-14) [66]
- FASUDIR - Friendly and affordable sustainable urban districts retrofitting (FP7, 2014-16) [67]
- IRH-MED - Innovative Residential Housing MED (Interreg MED, 2010-12) [68]
- NewTREND - New integrated methodology and tools for retrofit design towards a next generation of energy efficient and sustainable buildings and districts (H2020, 2015-18) [69]
- OpenHouse - Benchmarking and mainstreaming building sustainability in the EU based on transparency and openness (open source and availability) from model to implementation (FP7, 2010-12) [70]
- Eco-Quartier - French Label Eco Quartier (Eco-District) [71]
- Protocollo ITACA- Environmental label (Federal Association of the Italian Regions, with the scientific support of iiSBE and ITC-CNR) [72]
- QDM - Quartiers Durables Méditerranéens (Sustainable Mediterranean Neighbourhoods) [73]

Methodology

In accordance with the European resource efficiency and sustainable development aims there is a need to develop a framework based on a set of basic indicators going along with a recommended assessment method and a European marking model for the local context. It must have a groundbreaking approach covering all features along the building life cycle from planning and design to construction and commissioning and to operations and maintenance. For the aims and principles, a local assessment to be developed the following had to be kept in mind:

1. *The User* - focus on the user first with a commitment to design, construct, operate and maintain buildings to meet the users' practical and well-being needs.
2. *Sustainability* - the assessment had to cover all sustainability aspects that is environmental, economic, and social dimensions.
3. *Local Context* - building assessment systems had to embrace the local exclusive priorities, behaviours, traditions, and construction practices. This implied embracing local standards and regulations suitable to the local climate and accounting for the available natural resources and cultural design features. Each criterion had to be assigned a relative weight and a reference target adequate to the local conditions. The Rating Results value shrinks when systems are used outside their original contexts.
4. *Comparability* – the performance results had to be comparable within a points/target system.
5. *Simple to use* - the system had to find the adequate balance between the straightforwardness to use and the scientific/technical value. It had to be correct, clear, and observable. A system requiring complex computations or inaccessible data would request too much time and effort to be widely used.
6. *Stakeholders* - the system had to be adopted and used by different building sector stakeholders for different purposes namely:
   - As a design tool by establishing design priorities and objectives.
   - As a guidance in developing appropriate design strategies.
   - As a benchmark for the sustainable design guidance and decision-making processes.
   - As a project management tool to organise and structure environmental matters during the building development delivery.

Further it can be used by construction related SME's and workers, contractors, and building developers for the formulation of business strategies. The tool can be an aid to students, at universities and research Institutions, sustainable building experts and Energy Institutes and Energy Providers. Finally, it can be used for policy formation by public administration at national level dealing with incentives systems and technical aspects of sustainable buildings.

The HEART project research [15] contributes to a better grasp of the Green Building Rating Tool (GBRT) concept and its role for achieving sustainable building development. In addition, the objectives are:

1. To achieve sustainable development through the development of an effective green building rating tool for buildings in the Maltese Islands in dimensions terms used by existing global assessment tools but weighted according to the local context.
2. To provide a comparison of the various existing rating tools used over the world such as LEED, CASBEE, BREEAM, Green Star, PBRS, DNGB, SBtool and others.
3. Define the most appropriate tool based on the terms and criteria most applicable to the local context to be used throughout the whole development cycle.

Research Design for the HEART System

The aim of the research was to identify and weight the most important criteria considered for the development of a GBRT system for Malta to be used by local building professionals. It adopted a multidimensional design strategy that involved a variety of both qualitative and quantitative approaches. The research was divided into five different stages as follows:

1. *Literature Review* - A comprehensive literature review was undertaken to understand different existing global GBRT and assessment methods.
2. *Comparison of Assessment Tools* – Sixteen global tools were also briefly compared for their economic and process aspects. The following tools were analysed: BREEAM (UK), SBtool (Canada), LBC (USA), LEED (USA) GREEN GLOBES (USA), BEAM (Hong Kong), GREEN STAR SA (South Africa), CASBEE (Japan), HQE (France), GREEN STAR (Australia), GRIHA (India), GREEN MARK SCHEME (Singapore), 3 STAR (China), VERDE (Spain), ESTIDAMA PBRS (UAE) and DNGB (Germany). These were also compared to the EU Framework for sustainability Assessment of Buildings namely EN 15643 parts 1 to 4. The comprehensive list was narrowed down to seven main tools - namely BREEAM (UK-Europe), LEED (United States of America), CASBEE (Japan-Asia), GREEN STAR (Australia), ESTIDAMA PBRS (UAE), DNGB (Germany) and CESBA SBtool (Austria).
3. *Case Study* - Smart City Phase 1B LEED Silver Certified Case Study Results were used in the research to show how certification was achieved.

4. *Data Collection* - Twenty in-depth interviews were held with stakeholders and an online survey was distributed to local building professionals, architects, civil engineers, and building services engineers to establish the importance of the selected main criteria and their respective final weighting. One hundred and eighteen professionals participated in the online survey.
5. *Data Analysis* – The limited local expertise rendered analysis by the AHP method (pairwise comparison) not possible. SPSS package was used to analyse the collected data. The Simple Additive Weighting (SAW) and Complex Proportional Assessment (COPRAS) methods were used for the comparative multi criteria data analysis to weigh and develop HEEART – the High Environment Efficient Assessment Rating Tool for the Maltese Islands.

Figure 10: Sustainability Assessment Tools - Comparison (Sant)

Results

The criteria weighting system is fundamental step in the development of green building assessment tools. The SAW and COPRAS models were used to compute the multi-criteria weighting on the rank order results. Criteria data was collected on a Likert scale from 1 (highly unimportant) to 5 (highly important) (maximising) - and a Rank order scale from 1 (highest) to 8 (lowest Ranking) (minimizing) [15].

The Hypothesis testing was designed as follows:

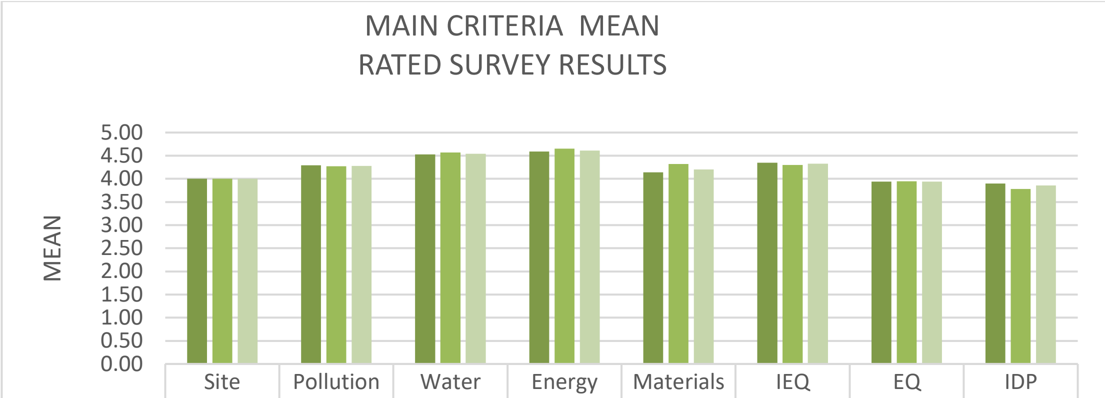
H_o *There is no difference in the mean rating scores, for the criteria are comparable and all criteria are of equal importance.*

H_1 *There is a significant difference in the mean rating scores, for the criteria are not comparable and some criteria are of higher importance than others.*

Both rated and ranked data Friedman test result exhibit a *p*value less than the 0.05 criterion thus hypothesis H_1 is accepted. Therefore, it can be generalised that the criteria are not comparable, and some criteria are of higher importance than others.

	Site	Pollution	Water	Energy	Materials	IEQ	EQ	IDP
A. & C.E.	5.05	4.56	5.52	6.41	4.63	4.13	2.81	2.90
M. & E.	5.57	5.11	5.57	6.57	4.05	4.35	2.76	2.03
Total	5.21	4.73	5.53	6.46	4.45	4.20	2.79	2.62

Figure 11 : Main criteria rank order survey results



	Site	Pollution	Water	Energy	Materials	IEQ	EQ	IDP
A. & C.E.	4.00	4.29	4.53	4.59	4.14	4.35	3.94	3.90
M. & E.	4.00	4.27	4.57	4.65	4.32	4.30	3.95	3.78
Total	4.00	4.28	4.54	4.61	4.20	4.33	3.94	3.86

Figure 12 : Main criteria mean rated survey results

Weighting Criteria and the HEEART Model Development

The rank order means scores were used to investigate the comparative importance among the criteria. Weighting factors were computed using the SAW and COPRAS methods. Both methods are based on the Criterion main score result expressed as a proportion of the Total Mean Rank Scores. An assessment score of 100 points was used to compute the credit point scores for the relevant criteria using the resulting weight factors. Weighting Factors were calculated on the RO means results. The HEEART assessment model is made up of 8 main criteria with a fixed number of points according to the weighting factor computed in the analysis. Maximum points achievable are 100 [15].

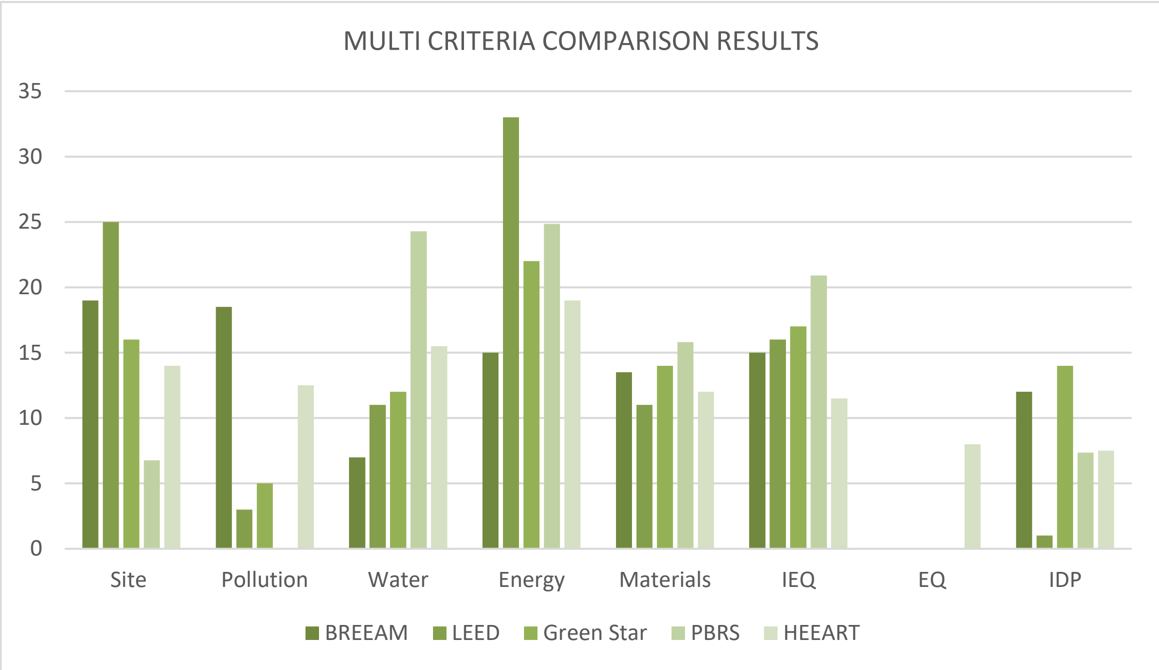


Figure 13 : *Results obtained for the Maltese GBRT system in comparison with the main GBRT systems (Note: economic quality (EQ), indoor environment quality (IEQ), site and integrated development process (IDP))*

Conclusions

The Maltese HEEART System is classified as a multi criteria-based tool that defines a system of assessing point values to a selected number of criteria/indicators. The scope of this system mainly targets non-residential projects and their surrounding environment. This system, as proposed, commences with a pre-certification assessment, and develops into a three-stage assessment at the:

- Design Stage
- Construction and Commissioning Stage (Completion/Handing over Stage)
- Operational stage (one to two years of operation)

The end-of-life must be catered for at the design stage by including an end-of-life plan for the building's maintenance, dismantling, demolition, and disposal. The system in Figure 15 defined the environmental, social, and economic aspects, and gave importance to the site and the integrated development process. The assessment is presented in three hierarchy levels:

Category Level: Environmental, social, economic, site and integrated development process.

Criteria Level: The eight criteria proposed for the local system, and which constituted the main scope of the study are energy, water, pollution, materials, economic quality (EQ), indoor environment quality (IEQ), site and integrated development process (IDP) are the eight criteria proposed for the local system. The relevant criteria for the Maltese assessment system were identified and their respective weights developed. This mainly depended on the criteria's importance ranking.

Indicator Level: Although discussed briefly the analysis was based on interview results; no conclusions can be made on the indicators as this was not within the scope of this study. However further studies are needed to conclude the relevant number and their relative weights to be included in the local system. Further investigation is needed to decide which prerequisite items must be included in the system [15] .

Ongoing works

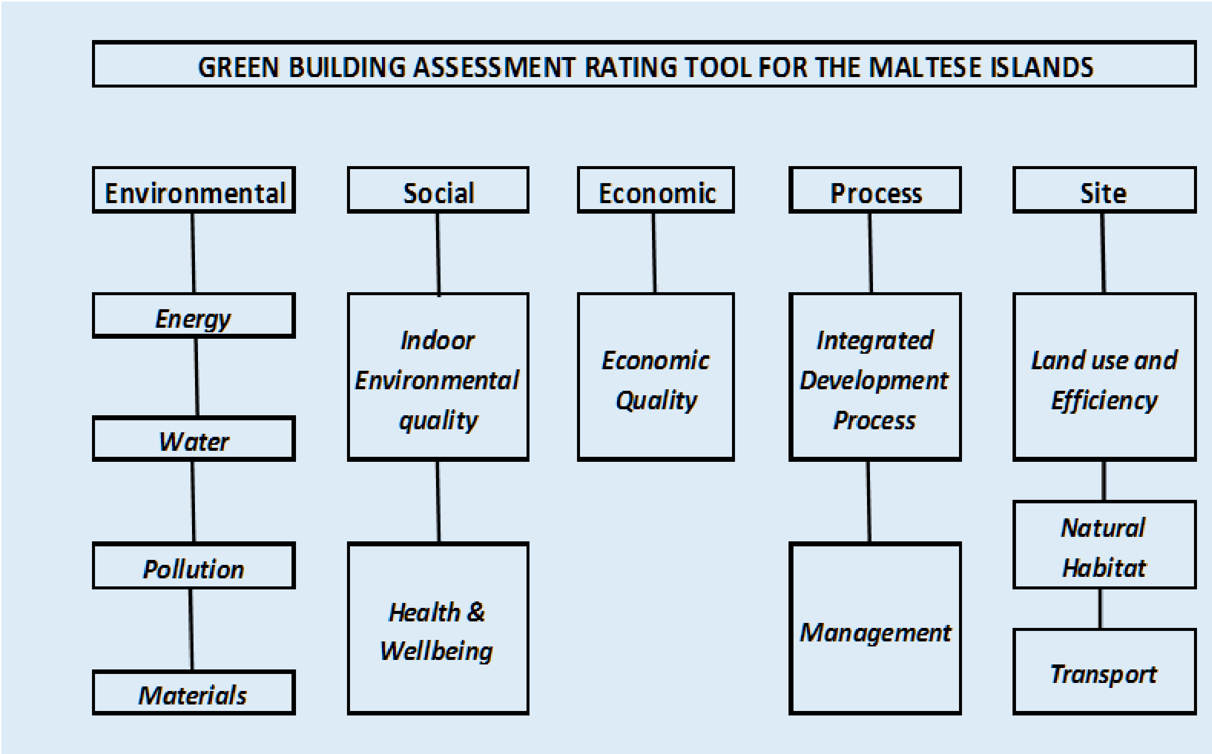


Figure 14: *The GBRT for the Maltese Islands*

A Green Building Assessment Tool is crucial for Malta as it is essential to meet the 2020 targets and move towards the 2050 vision where Maltese present and future generations *'live well within the limits of our islands'*. It is high time for Malta's building sector to embrace GBRT. Mandatory and rigorous assessment evaluations should be implemented for new, large-scale development. This is not only to minimise negative impacts on the surrounding environment, but also to ensure the delivery of maximum value for all stakeholders involved.

This approach offers significant advantages that are unlikely to be achieved through standard practices. It takes a holistic approach that encompasses all aspects of sustainable development, rather than solely focusing on minimising environmental impacts. By taking decisions that align with sustainability objectives and targets at the concept and design stages, many negative outcomes can be avoided. This research conducted for the development of HEART [15] goes beyond individual assessment frameworks by integrating criteria from multiple methodologies. It builds upon the strengths of each framework, resulting in a more comprehensive assessment approach that is tailored to Malta's context. The development of this GBRT system is based on scientific research, technical knowledge, and the collective input of multiple stakeholders. It considers Malta's unique culture, challenges, resources, priorities, practices, and institutions. Overall, this assessment framework provides a robust and contextually appropriate approach for evaluating sustainable building practices in Malta. Through the assessment of stakeholder feedback on LEED and BREEAM certifications in Malta, some relevant criteria and indicators were suggested, and others prioritised for their importance in the local context. Accordingly, 'transport' was amalgamated within the 'site' criteria and 'waste' was included in the 'pollution' criteria. Category levels are like those adopted in Europe, such as the DNGB and CESBA, however, the analysis resulted in differences in the weighting of each category. 'Energy' dominated the performance assessment and 'water' was ranked as the second most important criterion for the local assessment, a result which is justified through the scarcity of this natural resource on a local level. Considering that Malta is the EU member with the highest built-up area, 'site' was ranked as the third important criterion for the Maltese Green Building Assessment Tool. This was followed by 'pollution', 'materials', and 'indoor environmental quality'. These results are rational for Malta when considering the lack of natural resources, the land and water scarcity and the high level of air pollution (PM_{10} levels) present. The new tool, adapted to the local Maltese context, is intended to support industry stakeholders and professionals in the delivery of Green Buildings in Malta.

A Review of Existing Sustainability Assessment methods & Indicators for Buildings and Urban Areas [2]

The complete review is presented in the Annex report including the full technical report Literature review and market research.

General Consideration: Sustainability Assessment Tools & Public Buildings

This section aims to identify the most suitable method and set of KPIs for energy and sustainability plans in public buildings. By doing so, it seems to enhance their impact and effectiveness. The report draws on existing methods and conducts an analysis and review of these methods in relation to trans-national indicators and assessment methods for buildings and urban areas, specifically focusing on CESBA MED – Sustainable Med Cities [17], [19]. This review examines the sets of indicators used for assessing the sustainability of buildings and urban areas in different countries and regions. These indicators have been developed as part of various international and trans-national projects, as well as public assessment systems. The purpose of this review is to provide a comprehensive overview of these indicators and methods. Based on their relevance, operability, and affordability, a generic list of indicators is derived specifically for the Mediterranean context.

A. Available performance indicators under main issues and categories.
B. Presents a detailed overview of the existing performance indicators that have been developed within different European projects and public assessment systems for the sustainability assessment of buildings and urban areas.
C. Outlines the results from the classification of the existing performance indicators to then define two sets of indicators at (i) building and (ii) urban scale, as a catalogue. It also includes a description of the revised SBTool multi-criteria assessment methodology for the urban scale in the Mediterranean context.

Background [26] [2]

Buildings are the leading energy consuming sector, representing about 40% of the final energy consumption in Europe, and have a major impact on the natural environment. Energy efficiency improvement is a key European strategy to reduce the environmental impact of buildings. However, common energy efficiency plans do not fully exploit the potential for synergies that groups of buildings may offer (at the urban scale). The implementation of large-scale energy efficiency measures at the urban level: city, district, neighbourhood, or block level (e.g., district heating and cooling, photovoltaics, and solar thermal installations) have clearly demonstrated that a building scale is not an optimal approach for reaching significant and cost-effective solutions. On the other hand, decision making processes for the design and assessment of interventions are more complex at larger scales due to the number of the various sustainability themes that need to be addressed.

[2] CESBA Med Project Report D3.1.1. (2017) (Co-authored by the University of Malta – RPBorg)[26]

Indicators are metrics that can be used to determine how well the sustainability objectives are achieved. They can be expressed as:

- Numerical values (e.g., how much energy is used normalised per unit floor area of the building, so that it is possible to compare different buildings or against other benchmarks; how much water is consumed per building occupant or building occupant) or as
- Ratios and percentages (e.g., what percentage of renewables cover power or heat demand; what percentage of waste is recycled).

Performance indicators play a crucial role in benchmarking various attributes of buildings and urban areas. They aid decision-making, assess project requirements, and ensure compliance with regulations and norms. Depending on the user's intent, different indicators may be deemed more important as they support the diverse needs and priorities of stakeholders. For instance, in building design, the calculation of peak power demand or energy demand is a primary step to meet code requirements and minimise costs. Efforts may then be focused on architectural design, thermal envelope materials and components and electromechanical (E/M) systems. Additionally, indicators related to indoor environmental quality, such as thermal comfort (e.g., minimum, and maximum indoor temperature), visual comfort (e.g., daylight) and indoor air quality (e.g., different air flow rates and minimum fresh outdoor requirements).

Numeric metrics provide a straightforward way to gauge a building's energy performance, considering its characteristics, design, equipment selection, and operation. By comparing different design scenarios, these metrics can be used to optimise construction, operation, and assess energy refurbishment options. These indicators offer a quantifiable basis for decision-making and can effectively communicate choices to stakeholders. Indicators can be applied at various scales, such as the building or district level. In certain cases, there are shared indicators, where the values at the building scale contribute to the larger scale, such as a neighbourhood or district (Figure 15).

	Number	Name
Environment	*B.1*	*Energy*
	B.1.1	Operational Primary Energy Demand
	B.1.2	Delivered Energy Demand
	B.1.3	Renewable Energy on Site
	B.2	*Impacts*
	B.2.1	Global Warming Potential
Society	*B.5*	*Air Quality*
	B.5.1	Indoor Air Quality
	B.6	*Thermal Comfort*
	B.6.1	Summer Comfort without Cooling
	B.6.2	Thermal Comfort in the Heating Season
	B.6.3	Thermal Comfort in the Cooling Season
	B.8	*Acoustic Comfort*
	B.8.1	Acoustic Comfort
Economy	*B.10*	*Operational Costs*
	B.10.1	Operational Energy Costs

	Number	Name
Environment	*D.1*	*Energy*
	D.1.1	Operational Primary Energy Demand
	D.1.2	Delivered Energy Demand
	D.1.3	Renewable Energy on Site
	D.2	*Impacts*
	D.2.1	Global Warming Potential
Society	*D.8*	*Acoustic Comfort*
	D.8.1	Acoustic Environment
Economy	*D.10*	*Operational Costs*
	D.10.1	Operational Energy Costs

Figure 15: Breakdown examples of Building (left) and District (right) indicators [26]

In addition to building-level indicators, specific indicators can be selected to evaluate the energy status of a district or neighbourhood, particularly for smaller areas with up to 12 buildings. These indicators are useful for analysing energy networks and may include:

- Assessment of the district’s energy status, such as the percentage of energy demand that can be met with renewable sources, surplus electricity generated from renewables, and available storage capacity.
- Evaluation of the neighbourhood’s preparedness for central systems, including central heating, central cooling, and smart grids.

One of the most important industry-led initiatives to harmonise environmental performance indicators is that of the Sustainable Building Alliance (SBA http://www.sballiance.org). SBA assembled various representatives from major building assessment schemes (e.g., BREEAM, HQE, DGNB, SB Tool, LEED) and developed a harmonised framework of common metrics that focus on four life-cycle analysis indicators:

- Non-renewable primary energy consumption
- CO_2 equivalents
- Drinking water consumption and waste production
- Thermal comfort and indoor air quality

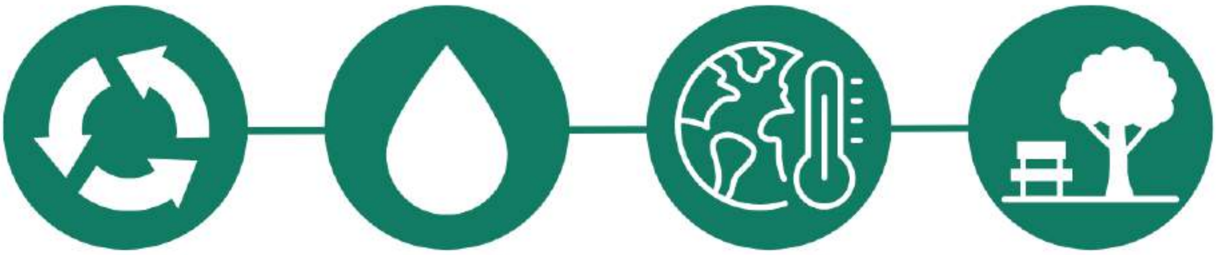
The Common European Sustainable Built Environment Assessment (CESBA) has been working to respond to the perceived confusion caused by the proliferation of various building assessment schemes, by bringing together various projects and platforms led by public authorities. A set of KPIs that form the basis for the CESBA 'building signature', include:

- Primary energy use
- CO_2 emissions
- Reused/recycled materials
- Water consumption
- Solid waste
- Building life-cycle costs
- Health and wellbeing factors (IAQ and thermal comfort)
- Monitoring/optimisation in operation

Over the past few years, the European Commission has recognized the importance developing a common EU framework of core indicators for the environmental performance of buildings and released the Communication on Resource Efficiency Opportunities in the Building Sector [74]. This

Communication identified the need for a common European approach to assess the environmental performance of buildings throughout their life cycle, considering the use of resources such as energy, materials, and water. The six macro-objectives that will be translated into indicators include:

- Greenhouse gases from life cycle energy use
- Resource efficient material life cycles
- Efficient use of water resources
- Healthy and comfortable spaces
- Resilience to climate change
- Optimised life cycle cost and value



The CESBA MED work focuses on identifying the most suitable transnational sets of indicators for the integrated assessment of public buildings and urban areas in the Mediterranean context, addressing the main dimensions of sustainability.

Issues and Indicators

The emphasis of CESBA MED [17], [19] is on the energy use of public buildings in the context of their surrounding urban area. This work considers various indicators for economic, environmental, and social issues, and numerous categories of commonly used indicators that are briefly discussed in the following subsections.

Economic Factors

Most decision-making processes are influenced largely by the project's economic aspects. Improving the building's energy performance has a direct impact on first and operational costs. For example, starting with the efforts to minimize loads one can reduce the size of equipment and thus minimize first cost, which includes materials, labour, overhead, VAT etc. Some design options and materials may last for the lifetime of the building, while others will extend over the lifetime of the components that may run over several years or decades. For high performance buildings, construction costs average 3% to 10% higher than standard alternatives but using energy efficient equipment or exploiting renewables will reduce operational costs by up to 40% to 50% compared to conventional buildings, with proper periodic operation and maintenance.

Different economic indicators are used for appraising the benefits and financial attractiveness of different design options and scenarios. For example, the simple payback period (PBP) is commonly used and easily understood in the market. More accurate, but more demanding methods are sometimes considered. These include the accounting rate of return (ROR) or average annual rate of return on investment (RRI), discounted cash flow (e.g., the net present value (NPV) and internal rate of return (IRR) methods). Life cycle costing (LCC) and analysis (LCCA) methodologies can be used to reach cost optimal levels. However, they are not easy to implement since they require information on energy prices, different material and equipment costs, and several relevant rates (e.g., variables and cash flow components) that may be difficult to define realistically under financial uncertainties.

A variety of indicators can be utilised to evaluate the advantages and financial viability of different design options for new buildings, as well as renovation scenarios for existing buildings.

Environmental Factors

Environmental issues that relate to new and existing buildings include the use of natural resources, various gaseous emissions (that are directly related to greenhouse gases and linked to global warming) and waste among others. They can impact the air, land (use, preservation, open available green areas), and water (consumption, pollution, waste). The rational use of freshwater resources, the exploitation of rainwater and wastewater treatment are some major environmental priorities, especially in the Mediterranean basin. The area also has a sensitive and significant biodiversity, with numerous indigenous plants that are suitable for landscaping and have reduced water needs.

Environmental issues associated with new and existing buildings encompass the use of natural resources, emissions of greenhouse gases contributing to global warming, and waste management. These issues have implications for air quality, land use and preservation, and water consumption, pollution, and waste. In the context of the Mediterranean basin, there is a particular emphasis on the responsible utilisation of freshwater resources, the harnessing of rainwater, and the effective treatment of wastewater. These practices are considered significant environmental priorities in the region. Moreover, the Mediterranean basin boasts a rich and delicate biodiversity, with a wide array of native plant species that are well-suited for landscaping and have lower water requirements.

CESBA MED primarily focuses on building energy use. The assessment of a building's energy performance commonly involves using indicators that quantify the breakdown of normalised final (site) energy consumption from different fuel sources, such as renewables, electricity, heating oil, and natural gas. It also considers primary (source) energy consumption to evaluate the environmental impact, including emissions. These indicators can be measured over different time intervals, with the annual basis being the most common, such as annual energy consumption or annual emissions. Additionally, these indicators can be used to evaluate different scenarios for equipment and system selection, aiming to reduce the overall energy consumption of the building and specific end-use energy consumption related to HVAC equipment, lighting, service hot water, major office equipment, appliances, plug loads, and vertical transportation. The emissions are directly linked to the energy sources used. Environmental emissions are typically expressed in terms of CO_2 emissions in kg (or equivalent) per unit floor area of the building or aggregated as total quantities.

Social Factors

In terms of social aspects, ensuring indoor environmental quality (IEQ) and the well-being of building occupants involves addressing thermal, visual, and acoustic comfort, as well as maintaining proper indoor air quality. To assess thermal comfort, temperature and humidity levels are key factors to consider. Detailed simulation results and monitoring data can be utilised to evaluate the prevailing conditions and identify issues such as overheating in the summer or excessive energy waste in the winter. Indicators, like the minimum indoor temperature in winter and the maximum indoor temperature in summer, can be used to assess compliance with desirable indoor conditions and provide and initial assessment of peak sensible loads. Similarly, indoor humidity levels can indicate the need for humidification in winter or dehumidification in summer, supporting the evaluation of peak latent loads. Ideally, spaces should have no more than 1% of the annual occupied hours exceeding or falling below the desired set point temperature. Common indicators used to quantify indoor thermal conditions and their impact on occupants include the predictive mean vote (PMV) and the percentage of people dissatisfied (PPD). These indicators help to further assess indoor thermal comfort and its effects on occupants. Visual comfort is an integral part of proper IEQ and a critical design parameter in commercial buildings since it improves productivity and overall functions. In terms of energy consumption, for some building categories, lighting may constitute a major final end-use and may also contribute to internal heat loads.

Another relevant indicator is the indoor air velocity that impacts thermal comfort conditions. Computational fluid dynamics (CFD) simulations can handle the complex phenomena and provide the necessary information to optimize the architectural and system design. CFD data visualization of spaces allows users to easily follow path lines and flow mixing resulting from mechanical or natural ventilation to evaluate the effectiveness of natural or mechanical ventilation systems. CFD may also be used to assess indoor air quality, outdoor pollution, and concentrations of contaminants, which are compared against standards and health regulations.

Air ventilation and circulation play a dominant role in achieving comfort conditions and securing the necessary amount of fresh (outdoor) air by natural, mechanical and/or hybrid ventilation. Minimum air flow rate of fresh outdoor air is a commonly used indicator, which depends on the building end-use, the number of occupants and the generation of indoor pollutants. Minimum requirements per person (m^3/h/person), according to the maximum occupancy (person/m^2 net occupiable floor area) to ensure proper indoor air quality are set by standards and technical regulations.

On an urban scale, transportation infrastructures such as public transport, availability of safe bicycle routes and suitable pedestrian streets are major elements for sustainable urban development. Public safety and security are also important social aspects that influence the well-being of residents and working visitors. Accessibility to public spaces (e.g., community centres and services, parks) and other services (e.g., broadband networks) are also very important social criteria.

CESBA MED Assessment System

Several European projects, as well as public and commercial programs and initiatives, have focused on addressing these issues and have put forth various methods, tools, and indicators. As a result, there is a wealth of knowledge available. However, there is a need to collectively examine these findings to establish a shared methodology and set of tools that are appropriate for refurbishing public buildings in the urban context of the Mediterranean. CESBA MED exploits available information from 14 transnational projects and public assessment systems. They are critically reviewed to develop a generic list of CESBA MED set of indicators at building and urban scale that will allow the sustainability assessment of public buildings and areas in the context of the Mediterranean area.

CESBA MED presents an assessment system composed by a generic framework (CESBA MED SN Generic Framework) and the locally contextualised assessment tools (CESBA MED SNTools). The reference assessment methodology adopted by CESBA is the SBTool of iiSBE that gives the possibility of a total contextualisation of tools to local conditions. The SBTool assessment methodology [75], originally developed for the building scale, is adapted for the application at urban scale. Finally, an integrated multicriteria CEBA MED assessment methodology is developed to connect the assessments at building and urban scale.

Transnational Methods & Indicators

CESBA MED is built upon the existing information and key findings from 14 transnational projects and public assessment systems (P.A.S.) that focus on energy efficiency at the building and urban scales. These projects and P.A.S. employ various indicators to evaluate the sustainability of buildings at different scales. The main projects and P.A.S. considered in this work are outlined in alphabetical order below. For more comprehensive information, please refer to the detailed CESBA MED Report D3.1.
1 [26]. [3]

CESBA MED Set of Indicators

Reference is made to an assessment method to investigate the Sustainability Assessment methodology for buildings and urban clusters. To identify a manageable number of indicators, practical considerations must address general aspects, such as stakeholders, clarity and accuracy, and specific energy and environmental factors such as energy demand, consumption, and emissions.

Stakeholders

A range of indicators can support the diverse needs and priorities of public authorities, policy makers and other public and private technical stakeholders (e.g., urban planners, investors, SMEs, grant

[3] *CESBA MED Interreg med project – Sustainable Med Cities (Co-author of this report Ruben Paul Borg – partner CESBA Med and co-author technical report and tool development)*[26], [65]

managers, owners, construction companies, solutions providers, and users) in their efforts to assess and improve the overall environmental, social, and economic performance of buildings. Ensuring indicator clarity is crucial to adequately support the decision-making process of specific stakeholders, without requiring extensive training to use them, and allowing for their immediate adoption.

Clarity & Accuracy

Effective indicators should be based on scientifically robust calculations, providing clear results that are easily communicated and understood by stakeholders. Simplicity and reproducibility should not compromise accuracy. However, incorporating higher complexity to extract essential data for these indicators may result in input uncertainties, leading to demanding data collection processes and simulations. These complexities will impose undue burdens and potentially limit the applicability of the indicators.

Primary vs Final Energy Consumption & Emissions

Primary energy, which is the source energy that has not been subjected to any conversion or transformation process (e.g., power plant), is used to produce the energy delivered to the building (e.g., electrical energy). Most European and national approaches consider primary (source) instead of final (site) energy consumption. For natural gas and oil, the multiplier to obtain primary energy is about 5% and 10% higher respectively. However, for electricity generated by conventional power plants, this may be three times higher, depending on the Mediterranean area considered. Evaluating primary energy is crucial for understanding resource depletion. However, from an occupant's or owner's perspective, final energy use directly impacts the building's operational costs. Final energy consumption is typically retrieved from energy bills and utilities for existing buildings or is estimated using appropriate calculation tools. Energy consumption may be normalised, for example, per unit floor area, unit volume or weather conditions, such as using heating- or cooling-degree days and may even be expressed for different end-uses at either the building scale and/or neighbourhood scale, such as heating or cooling. The definition of the reference floor area, such as gross floor area, heated floor area or useful floor area, using internal or external dimensions, should be carefully specified. Energy use per inhabitant is commonly used for comparison at large (national) level. The use of primary energy is necessary for calculating the environmental impact and CO_2 emissions. Environmental emissions are expressed in CO_2 emissions (or equivalent) in kg per unit floor area of the building and depend on the specific primary fuel. National or even regional conversion factors for calculating the primary energy consumption from calculated or measured final energy consumption depends on the fuel and the fuel mix for generating electricity. By comparing CO_2 emissions, it is possible to optimise the selection of equipment using different fuel sources.

Total vs Specific End-Uses Energy Consumption

Given the climate characteristics of the Mediterranean region, cooling energy holds particular significance within the scope of CESBA MED. Additionally, lighting and plug loads can also play a significant role in commercial and public buildings. It is crucial to consider both the overall and the specific breakdown of energy usage, depending on the specific end-uses (such as heating, cooling, ventilation, lighting, etc.) and the use of different energy carriers.

Embodied energy (EE) in building materials, equipment, and systems, is gaining increased attention as strict regulations, codes, building practices, and market advances result in decreasing energy consumption in buildings. It is crucial for new constructions and public works to select materials and equipment with low EE. Moreover, refurbishment projects must account for the EE of both the new and removed materials or equipment. However, there are several obstacles to when conducting this type of analysis, given that there is limited availability of local (national) tools and databases.

The CESBA MED indicators cover the following parameters:

- All economic, environmental, and social sustainability issues and aspects with an emphasis on environmental-energy related issues.
- Both Building (B) scale and Neighbourhood (N) scale.
- Different stakeholders

They also consider:

- The frequency of use in the existing projects considered during this work (i.e., how frequently used are the indicators).

They comply with the following requirements:

- Operational: calculate the indicators based on easily accessible open data and information from existing databases

- Affordable: calculate the indicator through a cost and time effective process
- Practical: support decision making processes to improve the sustainability of public buildings and urban areas
- Suitable: support certification processes at building and urban scale
- Relevant: for the Mediterranean context

The two sets of CESBA MED indicators at Building Scale and Neighbourhood (urban) Scale are defined with the intent to be used in assessment activities for the (Figure 16, Figure 17):

- Evaluation of the actual level of sustainability of urban areas and public buildings.
- Identification of the most cost-effective retrofit scenario for sustainable urban areas and public buildings.
- Evaluation of alternative design options for new sustainable urban developments and public buildings.
- Development of target-based action plans for sustainable public buildings.
- Sustainability certification of public buildings and urban areas.

Eventually one needs to consider a realistic number of indicators. To secure practical implementation aspects such as time constraints, complexity, and relevant accuracy for collecting the main input data, a realistic number of indicators need to be considered. This is the trend and current practice within several projects. For instance, ENERBUILD includes 16 KPIs, NewTREND [47], [69] includes 16 core KPIs, and FADUSIR includes 20 KPIs for building and district level.

Building Scale Indicators

(listed in alphabetical order)

ECONOMIC (ECO) ISSUE			
Category	**Criterion**	**Indicator (units)**	
Investment Costs	Capital cost	1	Additional costs for energy efficiency and sustainability (€)
		2	Investment costs (€/m²)
	Performance	5	Return on investment (%)
Life cycle Costs	Benchmarking & Targeting	1	Verifiable sustainable targets
	Cost benefit	2	Cost benefit analysis focused on sustainability
	Energy cost	3	Operational energy costs (€/m²)
		4	Operational energy costs aggregated (€)
	Total cost	6	Cost in operational phase (€)
		7 8	Life cycle costs (-) (€)
Management	Building operation	1	Communication and information management (%)
		2	Information and participation of users
		4	User information (-)
Quality	Benchmarking & Targeting	3	Setting verifiable environmental targets (-)
	Building energy performance	4	Energy optimization during planning (-)
	Cultural heritage	5	Monument or monumental value / Historical value (-)
	Process & Planning	6	Building works quality control
		12	Process and planning quality (-)
	Risk management	15	Long term stability of value (€)

ENVIRONMENTAL (ENV) ISSUE			
Category	**Criterion**	**Indicator (units)**	
Biodiversity	Building site	1	Ecological quality of the building site (-)
	Public spaces	3	Change in ecological value of the site, species (-)
Energy	Building vertical transportation	1	Escalators and moving walks design and efficiency (-)
		2	Lift design and efficiency (-)
		3	Stairs and ramps planning (-)
	Embodied energy	4	Embodied energy demand (kWh/m²)
	Final energy	5	Annual heat generation for space heating and DHW (kWh/m²)
		6	Cooling demand (kWh/m²)
		7	Delivered energy demand (kWh/m²)
		9	Heating demand (kWh/m²)
		10	Peak energy demand
	Primary energy	11	Abiotic Depletion Potential (kWh/m²)
		12	Consumption of non-renewable primary energy (kWh/m²)
		13	Operational primary energy (kWh/m²)
		18	Total primary energy demand (kWh/m²)
	Renewables	20	Renewable energy on site (%)
		21	Share of renewable primary energy in total primary energy demand (kWh/m²)
		22	PV-power plant (kWh/a)
Impacts	Eco-mobility	1	Eco-mobility potential of a building in its context (km/unit)
	Emissions	3	Acidification potential ($kgSO_2$-eq/m²)
		5	Annual CO2 emissions ($kgCO_2$/m²)
		6	CO2 emission factor heat supply (kg/kWh)
		8	Eutrophication potential ($kgPO_4$-eq/m²yr)
		9 11	Global Warming Potential ($kgCO_2$-eq/m² yr) (kWh/m²)
		13	Ozone depletion potential (kgR11-eq/m²yr)
		14	Photochemical Ozone creation potential (kgC_2H_4-eq/m²yr)
	Raw materials	24	Abiotic Depletion Potential elements (kgSB-eq/m²yr)
	Solid waste management	26	Accessibility to waste sorting facilities (%)
		27	Composting (-)
		28	Construction and demolition waste generation (kg/m²)
		29	Recyclable waste storage (m²)
	Water pollution	30	Water pollution due to material leaching (mg/m² yr)
Land Use	Preservation	2	Preservation of land (%)
	Soil sealing	4	Permeability of site / land (%)
Materials	ECO materials	1	Low-pollutant and low-emission materials (-)
	Emissions	2	Building materials and construction, OI3 index (-)
Water	Embodied water	1	Embodied water use (m³/m²)
	Freshwater	3	Operational water use (m³)
	Total water use	10	Operational water use and waste water (m³)
	Wastewater	15	Wastewater management (m³/m³)
		16	Water consumption & use of rainwater (-)

SOCIAL (SOC) ISSUE			
Category	**Criterion**	**Indicator (units)**	
Accessibility	Flexibility	3	Flexibility of residential buildings (%)
Acoustic Comfort	Noise - Indoor	1	Indoor A-weighted sound pressure level (dBA)
		2	Weighted sound pressure from ventilation (dBA)
Air Quality	Indoor air quality	1	Concentration of pollutants (µg/m³)
Thermal Comfort	Indoor conditions	1	Predicted Mean Vote (-)
		2	Predicted Percentage Dissatisfied (%)
		3	Thermal comfort in summer (-)
	Outdoor conditions	7	Microclimate index I (-)
Transport	Mobility & Alternative transportation	9	Shared mobility (%)
	Parking facilities	13	Bicycle Parking (%)
	Public transportation	17	Accessibility of public transport, stops and frequency (-)
		18	Accessibility to public transport, Lense index (-)
Visual Comfort	Artificial lighting	1	Illuminance (lx)
	Daylighting	2	Daylight factor (%)

Figure 16: Building Scale Indicators (Ref. CESBA Med Project) [21]–[26], [29]–[31]

Neighbourhood (urban) Scale Indicators

(listed in alphabetical order)

ENVIRONMENTAL (ENV) ISSUE

Category	Criterion		Indicator (units)
Biodiversity	Land preservation	2	During programming, design and before the beginning of the works; the land is maintained through mowings, prunings, maintenance of canals and hedges (yes/no)
	Public spaces	3	Change in ecological value of the site, species(-)
		4	Connectivity of green spaces (%)
		5	Diversity (yes/no)
		6	Ecological corridors and continuity (yes/no)
		7	Use of local plants (%)
		8	Vegetal areas (%)
Energy	Embodied energy Final energy	5	Annual heat generation for space heating and DHW (kWh/m²)
		7	Delivered energy demand (kWh/m²)
		8	Energy consumption (Toe/inhabitant)
		10	Peak energy demand
	Primary energy	12	Consumption of non-renewable primary energy (kWh/m²)
		13	Operational primary energy (kWh/m²)
		14	Primary energy for cooling (%)
		15	Primary energy for heating (%)
		16	Primary energy for public lighting (%)
		17	Total primary energy demand
	Renewables	18	Renewable electricity production (%)
		19	Renewable energy on site (%)
Impacts	Eco-mobility	1	Eco-mobility potential of a building in its context (km/unit)
	Effects on surrounding buildings	2	Impacts on surrounding buildings (%)
	Emissions	3	Acidification potential ($kgSO_2$-eq/m²)
		4	Acidifying emissions, Intensity (%)
		5	Annual CO2 emissions ($kgCO_2$/m²)
		6	CO2 emission factor heat supply (kg/kWh)
		7	CO2 emissions (tonnes CO_2-eq/yr)
		8	Eutrophication potential ($kgPO_4$-eq/m²yr)
		9 10 11	Global Warming Potential ($kgCO_2$-eq/m² yr) (-) (kWh/m²)
		12	Intensity of GHG emissions (%)
		13	Ozone depletion potential (kgR11-eq/m²yr)
		14	Photochemical Ozone creation potential (kgC_2H_4-eq/m²yr)
		15	Photo-oxidants emissions, Intensity (%)
	Light pollution	16	Light on properties (lx)
		17 18	Light pollution (-, %)
		19	Luminaire intensity (cd)
		20	Luminance (cd/m²)
		21	Upward Light
	Outdoor conditions	22	Monitoring of air quality (%)
		23	Thermal comfort of outdoor areas (%)
	Raw materials	24	Abiotic Depletion Potential elements (kgSB-eq/m²yr)
	Solid waste management	25	Accessibility to differentiated waste collection (%)
		26	Accessibility to waste sorting facilities (%)
		28	Construction and demolition waste generation (kg/m²)
	Water pollution	30	Water pollution due to material leaching (mg/m² yr)
Land Use	Preservation	1	Conservation of built environment (%)
		2	Preservation of land (%)
	Quality	3	Site quality (-)
	Soil sealing	4	Permeability of site / land (%)
	Spatial planning	5	Change of land use (-)
		6	Imperviousness change, Imperviousness coefficient (-)
	Urban design	7	Green zones & recreation areas (m²/inhabitant)
		8	Green zones & recreation areas density (%)
		9	Green zones & recreation areas proximity (%)
		10	Outdoor space (-)
		11	Population density (inhabitants/ha)
		12 13	Urban compactness (dwelling/m²) (m³/m²)
		14	Urban context (-)
		15	Urban conversion (%)
Materials	Emissions	2	Building materials and construction, OI3 index (-)
Water	Embodied water	1	Embodied water use (m³/m²)
	Freshwater	2	Intensity of water treatment (%)
		3	Operational water use (m³)
		4	Water consumption (l/inhabitant day)
	Rainwater	5	Dedicated network (yes/no)
		6	Intensity of rainwater usage (%)
		7	Landscaped and accessible retention ponds and ditches (yes/no)
		8	Rainwater collection from roofs (%)
	Total water use	9	Respecting streaming continuity (yes/no)
		10	Operational water use and waste water (m³)
	Wastewater	11	Intensity of wastewater treatment (%)
		12 13	Waste management & removal (l/inhabitant day) (%)
		14 15	Wastewater management (%) (m³/m²)

ECONOMIC (ECO) ISSUE

Category	Criterion		Indicator (units)
Equity	Housing value	1	Affordability of housing property (m²)
		2	Affordability of housing rental (%)
	Local economy	3	Support to local economy (%)
	Prevention of prejudice	4	Prevention of prejudice
	Social & Economic cohesion	5	Future evolution and modularity
		6	Gentrification index (-)
		7	Labor force participation (%)
		8	Potential Employment (%)
		9	Social housing ratio (%)
		10	Social mixing and solidarity based economy
		11	Unemployment rate (%)
Investment Costs	Capital cost	1	Additional costs for energy efficiency and sustainability (€)
		2	Investment costs (€/m²)
		3	Investment costs aggregated (€)
		4	Participation of local authority in the total investment cost (%)
	Performance	5	Return on investment (%)
Life cycle Costs	Benchmarking & Targeting	1	Verifiable sustainable targets
	Cost benefit	2	Cost benefit analysis focused on sustainability
	Energy cost	3	Operational energy costs (€/m²)
		4	Operational energy costs aggregated (€)
	Non- Energy cost	5	Operational non-energy costs aggregated (€)
	Total cost	6	Cost in operational phase (€)
		9	Life cycle costs aggregated (€)
Management	Building operation	1	Communication and information management (%)
		2	Information and participation of users
		3	Synergy management (-)
	Social & Economic cohesion	5	Environmental activities in primary school (%)
Quality	Architectural	1	Aesthetic quality (-)
		2	Enhance architectural, cultural and landscape patrimony (yes/no)
	Cultural heritage	5	Monument or monumental value / Historical value (-)
	Process & Planning	7	Community management (yes/no)
		8	Community planning (yes/no)
		9	Finalising the design phase (yes/no)
		10	Integrated design in the planning process (-)
		11	Internal project management (yes/no)
		12	Process and planning quality (-)
		13	Project management (yes/no)
		14	Working with skilled professionals (yes/no)
	Risk management	15	Long term stability of value (€)
		16	Risk management (-)
	Territorial management & Urban design	17	Urban complexity, Shannon-Wiener index (-)
Value	Flexibility & Adaptability	1	Flexibility and adaptability, during the life of the project (yes/no)
		2	Flexibility and adaptability, programming (yes/no)
	Process & Planning	3	Assessing the current situation (yes/no)
		4	Competent professional team
		5	Economic advantage of cluster in comparison to single buildings (-)
		6	Equipment and services pooling
	Social & Economic cohesion	7	Tourist frequency trends, seasonality overnight stays (%)
		8	Tourist frequency trends, seasonality tourists (%)

SOCIAL (SOC) ISSUE

Category	Criterion		Indicator (units)
Accessibility	Broadband communication network	1	Access to a broadband communication network, areas (%)
		2	Access to a broadband communication network, population (%)
	Flexibility	3	Flexibility of residential buildings (%)
		4	Flexibility use (%)
	Public space planning	5	Access to parks and open spaces (-)
		6	Adaptation to users practices (yes/no)
		7 8	Availability of green spaces (%, m²/inhabitant)
		9	Barrier-Free accessibility of the district (-)
		10	Community gardens (yes/no)
		11	Parks and vegetated spaces network (yes/no)
		12	Public space quality (yes/no)
		13	Shared community spaces (yes/no)
	Services & Leisure facilities	14	Access to services and facilities (%)
		15	Collective facilities and outsourcing of services (%)
		16	Community support (yes/no)
		17	Proximity to leisure facilities (%)
		18	Proximity to services (%)
		19	Proximity to services and leisure facilities (%)
		20	Social gatherings and common cluster activities (-)
	Street network	21	Cyclomatic complexity of the street network(-)
	Urban planning	22	Development and integration of land parcels (%)
		23	Homogeneity of the urban fabric (%)
Acoustic Comfort	Noise - Indoor	1	Indoor A-weighted sound pressure level (dBA)
	Noise - Outdoor	3	Building area over noise limit (%)
		4	Noise pollution, silence quality – day (%)
		5	Noise pollution, silence quality – night (%)
	Noise pollution management	6	Acoustics studies (yes/no)
Air Quality	Indoor air quality	1	Concentration of pollutants (µg/m³)
	Outdoor air quality	2	Number of days with bad air quality (days/yr)
Safety & Security	Energy & Management systems	1	Objective/subjective safety measures (-)
	Green production	2	Local production of food (m²/inhabitant)
	Mobility	3	Pedestrian safety paths (%)
Thermal Comfort	Indoor conditions	1	Predicted Mean Vote (-)
		2	Predicted Percentage Dissatisfied (%)
	Outdoor conditions	4	Exploitation of local resources: sun, daylight, wind (-)
		5 6	Heat island effect (-) (yes/no)
		7	Microclimate Index I (-)
Transport	Mobility & Alternative transportation	1	Availability of safe bicycle routes (m)
		2	Bicycle and pedestrian network quality (-)
		3	Bicycle facilities (-)
		4	Car sharing pool/station (yes/no)
		5	Contiguity of bicycle and car routes (%)
		6	Pedestrian streets and walkways, area (%)
		7	Pedestrian streets and walkways, length (%)
		8	Proximity to bicycle lanes and paths (%)
		9	Shared mobility (%)
	Parking facilities	10	Parking facilities (number/dwelling)
		11	Parking facilities, Off-street parking spaces (%)
		12	Parking places with innovative features (%)
	Public transportation	14	Access to public transport nodes, areas (%)
		15	Access to public transport nodes, population (%)
		16	Access to public transport, District Accessibility Index (-)
		18	Accessibility to public transport, Lense index(-)
		19	Dwellings with access to public transport (%)
	Street network	20	Connectivity of the street network (number/m²)
		21	Cul-de-sac roads and path ratio (%)
		22	Scale of the street network (m)
		23	Traffic modal split (%)
Visual Comfort	Artificial lighting	1	Illuminance (lx)
	Daylighting	2	Daylight factor (%)

Figure 17: *Neighbourhood (Urban) scale indicators (Ref. CESBA Med Project)* [21], [22], [23], [24], [25], [26], [29], [30], [31].

SBTool Multi-Criteria Assessment

The CESBA MED Generic Framework for Sustainable Neighbourhoods is based on the “SBEMethod” (Sustainable Built Environment Method) developed by iiSBE (International initiative for a Sustainable Built Environment). The SBEMethod is a generic multi-criteria analysis methodology for assessing the sustainability of the built environment. Starting from a set of assessment entries (criteria), the SBEMethod provides a final concise score about a building, urban area or territory overall performance. The SBEMethod [21], [22], [23], [25], [29], [31] constitutes the reference assessment methodology for the CESBA MED SN Generic Framework.

The SBEMethod [21], [22], [23], [25], [29], [31] is organised according to (Figure 18):

- Issues (describe general themes for sustainability assessment)
- Categories (address particular aspects of issues)
- Criteria (detail specific aspects of categories)

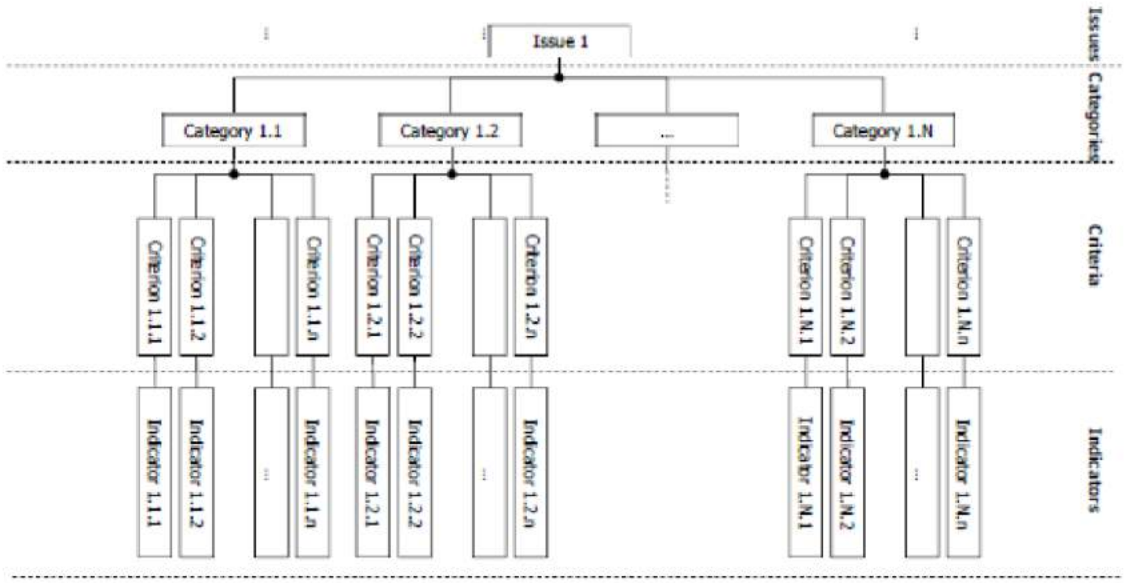


Figure 18: CESBA MED Tool - Issues, Categories, Criteria – Indicators. [21]–[23], [25], [29], [31]

Each issue includes a different number of categories, each one of them describing a specific aspect of the issue that it belongs to. Categories include different criteria, each of them describing a particular aspect of the corresponding category. Criteria represent the basic assessment entries used to characterize an urban area from the very beginning of the assessment process. The indicators quantify the performance with respect to each criterion. In principle, several indicators can be associated with the same criterion, since one can define multiple strategies to quantify the urban area performance regarding a specific criterion. However, in most cases, each criterion is generally associated with a single indicator. A final concise score summarises the overall performance of an urban area with respect to all criteria. The score is computed starting from indicator values following an assessment procedure that is based on three main steps, i.e., characterization, normalisation, and aggregation step. The relevant procedures are detailed in this report [21], [22], [23], [25], [29], [31]

Testing of the CESBA Med Tool on Pilot Projects

CESBA Med Pilot Project - Case Studies

The CESBA MED system was put into practice through nine pilot studies conducted in six countries (Table 7). These studies aimed to demonstrate the system's applicability in diverse settings, including different building uses and urban areas (such as social housing and19th century historic buildings). The studies also encompassed different scales ranging from a single building block to a university campus and various-sized urban neighbourhoods. Additionally, the system was tested on both renovation and new development projects, with some cases involving the assessment of multiple renovation scenarios.

The pilot studies had two main purposes. Firstly, they aimed to collaborate with local experts and municipalities to develop national versions of the tools. This involved selecting suitable indicators, translating the tools, and incorporating representative national weights for different sustainability issues and benchmarks for normalising the indicator values. This process allowed the existing default values in the national versions of the tools to be adjusted to better match local characteristics, such as energy use intensities for local buildings or water consumption in the area. Secondly, the pilot studies served as a final test phase to verify the practicality of using the selected KPIs in real-world scenarios.

The goal was to ensure that the input data required for building and urban audits are readily accessible, enabling consistent calculation of KPIs/ The national pilot studies also provided valuable insights into the sustainability indicators chosen by each national team, highlighting the priorities and emphasis placed by the participating municipalities.

National Tools

The Generic Framework tools are available in English, while the nationally contextualised assessment tools are available in different languages (i.e., Catalan, Croatian, French, Greek, Italian and Spanish). The national tools include the same KPIs, but use a different number of categories, criteria, and indicators (Table 9) that best fit in the national and local context and their sustainability priorities.

Table 7 : Overview of the sustainability issues, categories and criteria-indicators used in the generic framework (GF) and the national framework tools.

	GF	Italy (A)	Italy (B)	France (A)	France (B)	Spain (A)	Spain (B)	Malta	Greece	Croatia	Average
Building Scale											
Issues	7	7	7	7	7	7	7	7	7	7	7
Categories	25	15	18	8	8	19	21	11	16	15	15
Indicators	153	16	31	16	19	38	40	36	31	27	28
KPIs	13	13	13	13	13	13	13	13	13	13	13
Neighbourhood Scale											
Issues	7	7	7	7	7	7	7	7	7	7	7
Categories	23	14	20	11	13	16	20	20	16	20	17
Indicators	178	34	46	16	19	33	59	66	44	38	39
KPIs	16	16	16	16	16	16	16	16	16	16	16

Each team selected the indicators from the Generic Framework that were most relevant to their national sustainability priorities and that are commonly encountered regional and local issues.

For example, the generic framework for the neighbourhood scale includes a total of 23 categories and 178 criteria indicators, while the national tool in Greece uses a total of 16 categories and 44 criteria indicators.

The only set of criteria that is required and included in all national tools are the KPIs that represent internationally recognised sustainability assessment priorities. According to the pilot test results, the selected number of sustainability criteria averaged 28 indicators at building scale and 39 indicators at neighbourhood scale. Based on the number of selected indicators in Figure 19, the sustainability issue that received the most emphasis was ‘B-Energy and Resources’, accounting for 32% of the total indicators used at the building scale, while ‘G-Social Aspects’ accounted for 26% of the total indicators at the neighbourhood scale.

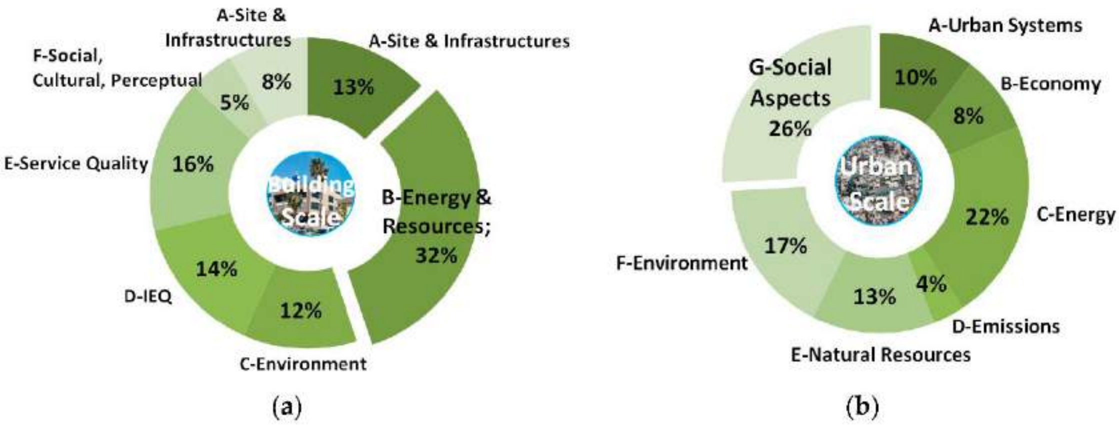


Figure 19: Overview of the average breakdown of the selected criteria-indicators used in the national tools for the seven sustainability issues for (a) the building scale; (b) the neighbourhood scale (CESBA Med project)

For each of the selected indicators, the national teams in collaboration with local committee experts specified the local benchmarks, i.e., the values that correspond to the appropriate local excellent practice (corresponding to “+5” in the normalized score), the minimum acceptable performance (corresponding to “0” in the normalized score) and below minimum standard (corresponding to “−1” in the normalised score).

This information was used to benchmark the values for each indicator and to normalise them on the -1 to 5 points scale. The benchmarks for the KPIs from the different regions are summarized in Table 8. The values can provide initial guidance during future developments and adaptations of similar tools in other regions. The empty cells in Table 8 (i.e., B.1.10 for embodied energy, C.3.2 for recycled solid waste, D.1.9 for ventilation rates) refer to cases with gaps in data due to missing information.

Table 8 : Summary of the key performance indicators (KPIs) benchmarks (minimum and best values) used in the national framework tools for the building and neighbourhood scales (Consideration of Different Mediterranean Scenarios).

Code	Key Performance Indicators (KPIs)	Units	Value	Italy (A)	Italy (B)	France (A)	France (B)	Spain (A)	Spain (B)	Malta	Greece	Croatia	Average
					BUILDING SCALE								
B.1.1	Primary energy use	kWh/m²/y	Minimum	80	140	48	140	225	292		310.6	90	165.7
			Best	30	23	0	0	70	58		87.6	55	40.5
B.1.2	Final thermal energy use	kWh/m²/y	Minimum	70	80	40	130	22	75		69.1	50	67.0
			Best	20	10	0	30	12	20		11.5	10	14.2
B.1.3	Final electrical energy use	kWh/m²/y	Minimum	30	23	40	140	75	70		99.4	30	63.4
			Best	20	5	0	0	20	30		29.1	0	13.0
B.1.5	Renewables in final thermal energy use	%	Minimum	30	25	25	10	30	30		16	20	23.3
			Best	100	50	100	100	100	100		80	90	90.0
B.1.6	Renewables in final electrical energy use	%	Minimum	40	35	10	10	40	40		20	5	25.0
			Best	100	75	200	100	100	100		100	90	108.1
B.1.10	Embodied non-renewable primary energy	MJ/m²	Minimum	2500		180	900				6230	14	1964.8
			Best	1000		90	504				3000	3	919.4
B.4.5	Water consumption for indoor uses	m³/occupant/y	Minimum	40	47	40	90	100	11		6	5.5	34.2
			Best	25	23	20	20	20	5		1.5	2	13.8
C.1.3	Global warming potential	kg CO_2 eq./m²/y	Minimum	30	28	20	80	30	96.31		7.5	40	43.1
			Best	0	5	5	5	10	19.26		2	5	5.9
C.3.2	Solid waste categories recycled	%	Minimum	50	14	0.4	0.4	15			57	28	23.5
			Best	80	100	1	1	100			100	100	68.9
D.1.9	Ventilation rate	Lt/s/m²	Minimum	10	0.35	0.5		6			0.29	2.77	3.3
			Best	20	0.49	0.9		12			0.83	6	6.7
D.2.2	Thermal comfort index	%	Minimum	10	10	10	10	25	10		25	25	15.6
			Best	0	6	5	0	5	0		5	5	3.3
G.1.4	Operational energy cost	€/m²/y	Minimum	20	10.7	15	15	60	35		18.9	7.5	22.8
			Best	10	1.75	5	5	40	10		4.7	1.5	9.7
G.1.5	Operational water cost	€/m²/y	Minimum	5	1.55	10	13		5		0.59	0.5	5.1
			Best	1	0.7	3	2.3		1		0.15	0.2	1.2
					NEIGHBOURHOOD SCALE								
A.1.7	Land conservation	%	Minimum	0.5	7	15	10	4	10	10	10	2	7.6
			Best	2	42	30	20	15	20	28	20	10	20.8
B.3.3	Operational energy cost for public buildings	€/m²/yr	Minimum	7.4	10	14	14	20	13.56	100	17.7	100	33.0
			Best	4	3	3.5	3.5	10	3.33	0	4.1	0	3.5
C.1.1	Total final thermal energy consumption for buildings	kWh/m²/yr	Minimum	70	80	40	50	75	76.23	50	314	100	95.0
			Best	30	10	0	0	20	33.8	0	21.1	50	18.3
C.1.4	Total final electric energy consumption for buildings	kWh/m²/yr	Minimum	50	23	12	55	70	29.85	25	64.2	75	44.9
			Best	20	5	0	5	20	10.88	5	7.9	50	13.8
C.1.7	Total primary energy consumption for buildings	kWh/m²/yr	Minimum	322	72	40	140	225	152	50	461.9	100	173.7
			Best	242	50	0	0	70	15	15	38.2	70	55.6
C.2.1	On-site renewables in total final thermal energy consumption	%	Minimum	20	25	25	30	25	25	25	4	5	20.4
			Best	100	50	100	100	90	90	90	14	30	73.8
C.2.7	On-site renewables in total final electrical energy consumption	%	Minimum	20	35	25	35	15	15	35	1	20	22.3
			Best	100	75	200	75	75	75	75	47	35	84.1
D.1.2	Total GHG Emissions from energy use in buildings	kg CO_2 eq./m²/yr	Minimum	22.5	13	20	30	30	30	80	46	22	32.6
			Best	0	11	5	10	10	10	30	5	15	10.7
E.1.6	Water consumption in residential buildings	m³/occupant/yr	Minimum	65	47.45	40	68	150	150	15	62.1	250	94.2
			Best	61	23.7	20	30	40	60	5	18.6	100	39.8
E.1.7	Water consumption in public buildings	m³/m²	Minimum	1	1.3	5	1.1	15	15		0.65	5	5.5
			Best	0.5	0.6	2	0.4	5	5		0.33	3	2.1
F.1.3	Recharge of groundwater through permeable paving/landscaping	%	Minimum	20	40	20	20	20	20	20	15	20	21.7
			Best	40	60	70	100	70	70	100	80	80	74.4
F.2.3	Ambient air quality (PM10) above acceptable limits	days/yr	Minimum	35	35	30	30	15	15		35	20	26.9
			Best	25	0	11	11	11	11		0	15	10.5
G.2.1	Proximity of residents to public transport	%	Minimum	70	60	50	0	30	30	30	50	5	36.1
			Best	100	100	100	100	100	100	100	100	40	93.3
G.2.4	Pedestrian & bicycle network	m/100 inhabitants	Minimum	14	43	15	200	20	5	5	2	0	33.8
			Best	42	129	40	50	80	40	40	20	500	104.6
G.4.2	Proximity of residents to key services	%	Minimum	80	30	30	30	30	50	50	50	20	41.1
			Best	100	80	100	100	80	100	100	90	70	91.1
G.6.3	Community involvement in urban planning (qualitative score)	level (score)	Minimum	0	3	0	0	0	0	0	0	0	0.3
			Best	5	5	5	5	5	5	5	5	3	4.8

The weights used for each one of the seven sustainability issues from 1 (less important) to 3 (most important or more relevant) defined in the national versions of the tools reflect the local priorities, policies, or project intent. As summarized in Table 9, for the building scale, the sustainability issue “B-Energy and Resources” along with “C-Environment” are the two most prominent issues, averaging a total of ~80%. For the neighbourhood scale, lower weights were consistently used for “B-Economy” illustrating that once there is a commitment for sustainable development, the economic criteria have a lower priority. Sustainability issue “C-Energy” holds the highest overall pilot average. Nevertheless, the pilot regions had different priorities, and thus invested varying efforts, as is evidenced by the allocation of higher or lower weights.

Table 9: Summary of the weights on different sustainability issues used in the national framework tools for the building and the neighbourhood scales.

Sustainability Issues	Italy (A)	Italy (B)	France (A)	France (B)	Spain (A)	Spain (B)	Malta	Greece	Croatia	Average
Building Scale										
A-Site and Infrastructures	0.0%	0.0%	0.0%	0.0%	4.9%	11.6%	7.0%	6.5%	7.6%	4.2%
B-Energy and Resources	58.0%	69.8%	72.0%	72.0%	62.9%	54.9%	31.6%	28.5%	51.2%	55.7%
C-Environment	23.0%	24.3%	25.0%	25.0%	19.5%	20.4%	23.6%	36.6%	19.5%	24.1%
D-IEQ	11.0%	4.2%	2.0%	2.0%	2.1%	1.5%	2.0%	0.5%	8.0%	3.7%
E-Service Quality	0.0%	0.0%	0.0%	0.0%	7.9%	8.1%	20.7%	12.6%	3.2%	5.8%
F-Social, Cultural, Perceptual	0.0%	0.0%	0.0%	0.0%	1.9%	2.7%	12.0%	4.3%	5.1%	2.9%
G-Economy	8.0%	1.8%	2.0%	2.0%	0.8%	0.8%	3.1%	11.0%	5.5%	3.9%
Neighbourhood Scale										
A-Urban Systems	11.6%	10.4%	18.9%	0.0%	6.5%	10.2%	13.5%	10.8%	12.2%	10.4%
B-Economy	1.7%	6.6%	5.0%	1.8%	9.1%	3.6%	1.8%	4.2%	4.6%	4.3%
C-Energy	41.1%	18.4%	30.5%	28.2%	26.7%	25.9%	16.2%	33.7%	21.5%	26.9%
D-Emissions	6.9%	14.3%	23.6%	33.9%	7.3%	12.7%	5.8%	14.7%	13.3%	14.7%
E-Natural resources	6.9%	14.1%	3.4%	8.7%	7.3%	10.1%	11.7%	11.5%	14.3%	9.8%
F-Environment	18.3%	15.7%	9.4%	9.9%	31.3%	23.8%	28.7%	18.2%	9.0%	18.3%
G-Social Aspects	13.4%	20.5%	9.1%	17.4%	15.4%	13.6%	22.3%	6.9%	25.0%	15.9%

Note: Cells a green highlight identify the Issues with the Highest Weight in each national tool

Case Study: The University of Malta Campus and Office Building (Building and Urban Scale) [17], [18], [28]

- Description: University of Malta Campus (UM) centrally located on the island composed by 14 faculties, 8 institutes, 12 centres, 3 schools and a sports complex Vision: to provide educational facilities in a safe environment; attaining sustainability at building scale and at urban neighbourhood scale; wellbeing for the community on campus; serving as a hub with various facilities including office spaces, accommodation, library, etc.
- Unique specific situation: it is Malta`s only university and students come from all over the island; university is composed of a mixture of buildings constructed from 1960s-to date using different systems and construction methodologies; campus includes refurbished buildings and is a dynamic space with new buildings and faculty buildings; abundance of open space and piazzas
- Challenges: The neighborhood is publicly funded; high population density puts pressure on infrastructure (communication, waste, water, energy); difficulties in adapting and modifying the older buildings to meet current trends and requirements since buildings are always in use
- Solutions: rooftops fitted with solar panels to reduce electrical energy consumption; state of the art VRF systems (Variable Refrigerant Flow) on newer buildings to fine tune the thermal comfort of the buildings

- Lessons learned: how to improve transport systems; improvement in the management of green public areas; gaps in the benchmark were addressed with reference to urban areas in similar climatic zones
- Efforts: installation of solar panels on all roofs led to a shift towards saving in energy and improved energy managing; various buildings on campus are zero energy buildings; public transport was improved and upgraded; reduced demand for parking on campus and reduced traffic congestion; campaigns to promote waste separation; sustainable management of space; new buildings on campus designed with sustainability principles.
- Target group: students, administration, technical staff, academics
- Financing: estimated invested budget of the local community for the neighbourhood 1.2 Mio Euro
- Success: during the sustainable audit and the use of the Sustainable Neighbourhood (SN) tool knowledge and data about water resources, energy consumption, waste management, transport data, economic data and social data were gathered; tool highlights the challenges the neighbourhood is facing;
- Future perspective / Recommendations: by conducting the sustainable audit on the UM campus, certain challenges were highlighted by the tool; improving waste management systems and transport across UM; promoting carpooling and use of public transport; better use of water resources, etc; sustainable committee C-SUM was set up in 2018;
- The full details of the University of Malta Case Study can be retrieved through the CESBA Med Project Reports. [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31], [32]

The CESBA Med Tool and its Application to Building and Urban Areas: Discussion [2]

Municipalities and public authorities aiming to achieve SDGs at local, regional, national, and international levels face the challenge of addressing complex issues. To facilitate their efforts and overcome these challenges, they require flexible and user-friendly methods and tools. CESBA MED is a newly developed multicriteria assessment system that is open and adaptable. It is based on the UN and EU SDGs and can be used to quantify and incorporate sustainability issues into decision-making processes. CESBA MED [32]supports users through the entire process, assisting in initiating, organising, adapting, evaluating, and identifying the most effective sustainable renovation strategies for buildings or neighbourhoods. Additionally, it helps monitor progress towards sustainability targets. Compared to other sustainability audit and rating systems, CESBA MED offers an open-source assessment system for measuring sustainability at the building and neighbourhood scale in a harmonised approach. Cities can easily adapt the tool to a local context by selecting and using the most suitable indicators, and incorporating weighting factors that reflect local targets, priorities, and policies. By having a tailored system, the sense of local ownership is strengthened, and the assessment results are comparable among cities at national and transnational levels. At building scale, CESBA MED addresses seven sustainability issues, including: A-Site and infrastructures, B-Energy and resources, C-Environment, D-Indoor environmental quality, E-Service quality, F-Social, cultural, and perceptual aspects, and G-Economy, which are described and quantified with 153 sustainability criteria/indicators. Among them, 13 KPIs have been selected as mandatory indicators, which represent the priority sustainability transnational issues. At the neighbourhood scale, seven sustainability issues are addressed, including: A-Urban systems, B-Economy, C-Energy, D-Emissions, E-Natural resources, F-Environment and G-Social aspects, which are described and quantified with 178 sustainability criteria/indicators, including 16 KPIs.

The generic framework and common tools are available in English and different languages, while the assessment and rating approach have been contextualized to national (local) context for Croatia, France, Greece, Italy, Malta, and Spain [17].

Nine pilots performed in six Mediterranean countries demonstrated the applicability and adaptability of the CESBA MED system in practice for diverse applications at different scales and verified the practical use of the KPIs in the field. The assessment system can be used to carry out a sustainability diagnosis of buildings and neighbourhoods, to set up performance targets and to assess suitable retrofit or new development scenarios, to integrate sustainability in urban planning efforts. At this stage, CESBA MED does not include specific cost-related information for the various scenarios. Future work will consider the integration of relevant information since this will add practical value and facilitate the cost-benefit analysis for implementation. Furthermore, although the pilots provided sufficient confidence in the method, additional work will be necessary to test all the indicators included in the generic framework. In some cases, it may be necessary to reconsider some indicators. For example, A.2.4 Extent and connectivity of bicycle paths are expressed in km/1000 residents. Thus, an area with a very low number of inhabitants will result in very high value for A.2.4, even for a small bicycle route. Although this will not be an issue in a densely populated urban area, it may be more appropriate to consider an indicator expressed as km/resident. Except for certain KPIs, in cases that a specific indicator may not be appropriate to the local context, one can adapt the existing indicator to a more suitable one, provided that the benchmarks are also adjusted accordingly, along with the weighting factors, if necessary. In other cases, one may wish to use alternative indicators to quantify a criterion. For example, there are several indicators to evaluate environmental impacts (e.g., using the quantities of GHG emissions or the global warming potential), energy consumption (e.g., expressing the energy use intensity per unit area or per unit volume at building scale or per capita at neighbourhood scale), or thermal comfort conditions (e.g., using the standard effective temperature—SET or the predicted mean vote—PMV), and so on.

Except for KPIs, in situations where a specific indicator may not be suitable for the local context, it is possible to adapt the indicator or choose an alternative one, adjusting the benchmarks and weighting factors accordingly. For example, different indicators can be used to assess environmental impacts (e.g., GHG emissions or the global warming potential), energy consumption (e.g., energy use intensity per unit area or per unit volume at building scale or per capita at neighbourhood scale), or thermal comfort conditions (e.g., using the standard effective temperature – SET or the predicted mean vote – PMV). While using multiple indicators may seem flexible and advantageous, it may not be practical for local authorities targeted by CESBA MED. These authorities require a straightforward and easy-to-implement tool that considers their limited resources and expertise in understanding the advantages and disadvantages of selecting and using different indicators and alternative paths.

To facilitate implementation, the CESBA MED system is complemented by an electronic training system. This system offers open access to educational materials in multiple languages, catering to various target groups such as engineers, technical staff, decision-makers, and policymakers. These materials can be utilised for self-learning and in-house education, training, and professional development. They aim to enhance the knowledge and understanding of different sustainability issues and indicators. By strengthening the capacity of local stakeholders, the training system assists in developing effective policies and implementing integrated local action plans for sustainable urban development.

Based on the findings from the project, eight actionable and clear recommendations were developed to encourage policymakers in Europe to promote a new culture of the built environment. Additionally, there are already some notable good practices in place that demonstrate the potential applicability of CESBA MED.

For example, Protocollo ITACA [55], [72]an environmental label promoted by the Italian regions for the evaluation and classification of buildings, is based on the transnational building scale tool [75]the reference assessment methodology adopted by CESBA MED. Since 2004, it was accepted by the Conference of Presidents of the Italian Regions and has been contextualised and used at local level by several Italian regions. Since 2015, Protocollo ITACA is the legally binding, Italian national standard for the assessment of the sustainability of buildings. Similar statutory audit obligations and regulatory actions for buildings may be adopted in other countries to help implement the European initiative level(s), and extended for neighbourhoods, cities, and regions. Along these lines, the City Council of Sant Cugat del Vallès in Spain is using the CESBA MED method in the sustainable development of new buildings and urban areas. For example, during the design phase of new urban areas, developers are requested to provide data to calculate CESBA MED indicators, to assess their proposals.

The CESBA MED approach developed for the Mediterranean region for building and urban scale assessment, has been adapted to the regional and national scales. In Malta, the CESBA MED tool has been developed by a team at the University of Malta's Faculty for the Built Environment, and SBE Malta and applied to university campuses and buildings with the collaboration of the University of Malta Committee for Sustainability (CSUM). It has been further adapted to wider applications in public buildings, and church complexes. The ambition is to facilitate and improve the effectiveness and impact of action plans and policies, towards a sustainable future for all.

Conclusions

The full literature review and market research report includes reference to the CESBA platform and to best practice examples based on KPIs and other indicators for the assessment of sustainability. This background and literature, best practice, and adaptability to the Mediterranean and Maltese context are used as the basis for the sustainability assessment in the present study.

The market research is based on a review of assessment methods to measure sustainability at the building and urban scale, referring to practical case study examples. This method allows us to set the scene for the sustainability assessment of buildings and spaces and urban areas in Malta, in a Mediterranean context. It allows for the assessment of new build and retrofit projects. The review highlights the importance of key performance indicators and other indicators which are used to define sustainability, based on a quantitative assessment. The assessment highlights the importance of a rigorous approach which requires data and information gathered and its assessment using recognised methodologies to ensure an adequate comparison and review. The public and stakeholder participation in the process is key.

WP 2: Comprehensive Energy Efficiency Assessment: From Data Collection, Modelling to a Building Certification Process

In WP 1, the focus was primarily on assessing the existing building stock in Malta to prepare for the next phase, WP 2. WP 2 involves modelling a case study building to establish benchmarks for its retrofitting towards achieving near zero operational carbon status.

The objectives initially covered in WP 1 will continue to be developed in WP 2. In WP 1, quantitative data was collected, structured, and studied, to ensure a comprehensive analysis of the existing building stock. Additionally, a series of technical case studies on net zero carbon building frameworks from other countries were examined. This information helped the team to establish a benchmark and compare the retrofit targets that need to be met for the selected case study.

After extracting data from WP 1, a thorough evaluation was conducted to determine the appropriate energy uses for the selected building. Additionally, the parameters most effective in optimising the energy performance of the case study building in WP 2 were identified. To further inform the study, an energy assessment of the building was carried out, listing potential energy efficiency and renewable energy measures for the block. These measures were identified based on a comprehensive market study and a thorough review of relevant literature. The objectives of this work package are as follows:

- Selecting types of energy uses
- Validating the framework through building energy modelling
- Defining a methodology for calibration and estimation of energy efficiency
- Formalising benchmarks - net zero carbon building Return on Investment (ROI) and Life Cycle Costings (LCC)
- Reporting for a High Performance Buildings.

Introduction to the Case Study

The HSBC head office premises in Qormi was selected as the typical case study office building for conducting building energy modelling (BEM). The purpose of this modelling is to demonstrate an approach that local stakeholders can use as a guide when retrofitting office buildings to achieve nearly zero-carbon status.

The HSBC building, depicted in *Figure 20*, is being considered as a prototype for establishing a methodology to quantify operational energy performance improvements using building physics energy modelling. This methodology would involve implementing a combination of energy efficiency measures and setting sustainable operational energy performance benchmarks for buildings undergoing energy retrofitting. Furthermore, since the building is currently undergoing renovation, the feedback obtained from the building energy modelling exercise can be directly shared with the project designers. This allows for the identified measures to be incorporated as part of an integrated design process approach (refer to [76], [77], [78], [79]).

Figure 20: The HSBC head offices premises in Qormi

Building Energy Modelling (BEM) Background

The BEM Software Used

The building energy modelling (BEM) software used in this study is EnergyPlus [80], [81], which is a state-of-the-art and open-source physics-based software simulation of building energy use. As an input, EnergyPlus takes as a description of the building parameters in terms of [82]:

- **Geometry and form**, which are represented using a 3D model of the building. The 3D model can be extruded from existing 2D CAD floor plans, given that the height of each floor is known.

- For **envelope properties**, it is important to consider the U-values of the wall, roof, and glazing. For these, the rule is that the lower the U-value, the better the insulation levels of the building element. Hence, the lower the U-value, the less heat gain or heat loss to or from the building via thermal transmission. Furthermore, the glazing shading configuration and the glazing Solar Heat Gain Coefficient (SHGC), which is a measure of how well the glazing is protected from solar radiation, also need to be input into the software.

- **Equipment** considerations included lighting, HVAC, refrigeration, water heating, renewable generation system configurations, component efficiencies, and control strategies.

The following are important equipment parameter inputs for the office building considered:

i. **Space heating and cooling** coefficient of performance (COP) for the space heating and cooling heat-pump system. COP is the ratio of how much useful heat (or cold) a heat pump will produce with a given electrical energy input. For example, if one installs a 15,000 btu/hr heat pump (approx. 4.5 kW heat pump) with a COP of 2, and it is powered at full load with 4.5 kW of electrical power, the heat pump produces 9 kW worth of heat during heating, or 9 kW of heat is removed during cooling. The higher the COP, the better the efficiency of the heat-pump.

ii. **Lighting** can be modelled using a normalised power density approach, defined as power (W) per square meter of floor area per 100 lux of illuminance. A typical value of illuminance for general office work is 500 lux. The higher the efficiency of the lighting system, the lower the normalised power density. Lighting consumption is schedule driven.

iii. **Plug load equipment** can also be modelled in terms of power density with units W/m^2 and its consumption is also schedule driven.

iv. **Operation and Indoor Environmental Quality (IEQ)** entails set-points, that is, the use and operation of the building, including hourly schedules for occupancy, lighting, plug-loads, and thermostat settings. Heating and cooling comfort temperature set-points during occupancy and the mechanical air changes per hour to be met are important parameters inputted in the software and have a high impact on energy consumption. It is important that, in line with the new EPBD [9] which gives priority to comfort and indoor air quality (IAQ), these comforts and IAQ parameters are declared, compliant with local regulation/ EN standards and it is ensured that they are met when defining a benchmark for improved energy performance of a building.

Figure 21: Inputs to a building energy model [121]

The main inputs for a building energy model are summarised in Figure 21. EnergyPlus integrates the inputs from these building features with information from the provided weather file. The program uses a dynamic energy modelling approach based on physics equations to calculate the resulting energy performance of the building, along with related metrics like occupant comfort. BEM programs conduct a full year of calculations on annual, monthly, hourly, or even sub-hourly time resolutions. To ensure a dynamic and systems-integrated approach to modelling, the program considers system interactions like the ones between lighting and heating/cooling. Figure 22 illustrates the general data flow for dynamic building energy modelling software tools.

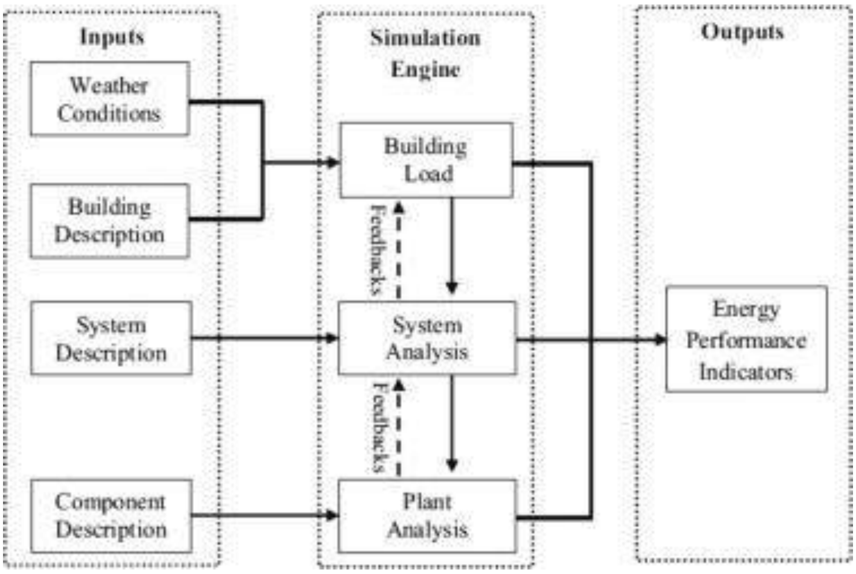


Figure 22: General data flow and main procedure of detailed simulation [122]

The BEM Software Applications

BEM applications for energy renovation include [82]

Architectural Design

To quantify how changes in the building envelope impact the energy performance of the building via the application of passive measures such as insulation and shading impact.

HVAC Design and Operation

Considering the often large and intricate nature of commercial building HVAC systems, BEM serves as a valuable tool for mechanical engineers. It aids them in retrofitting HVAC systems that efficiently meet building thermal loads and in comprehending the potential energy savings associated with upgrading to different options. Notably, the implementation of passive measures positively influences HVAC system size. A well-designed passive building exhibits significantly reduced thermal loads, allowing for the quantification of HVAC size reduction in EnergyPlus, which is then reflected in the installed HVAC systems. This reduction in size not only leads to cost savings in capital expenses but also has the potential to enhance system efficiency. EnergyPlus also proves beneficial in designing and testing control strategies for these HVAC systems.

Building energy performance indicator benchmarking

Once the energy efficiency measures to be implemented for a building under study are identified, an annual energy performance-based indicator (for example in kWh/m^2/year) for the building can be established. This enables building owners and management to compare the energy performance of their building with established benchmarks and to identify how well their building is performing compared to other buildings having a similar typology. Most importantly, building owners can compare their actual energy consumption to this benchmark and take the required actions if their actual energy performance is inferior to this benchmark.

Figure 23 identifies the main BEM applications as a multi-purpose tool for achieving energy efficiency, supporting projects at the level of individual buildings (design, control, rating, financial incentives) and building stocks (program development, research).

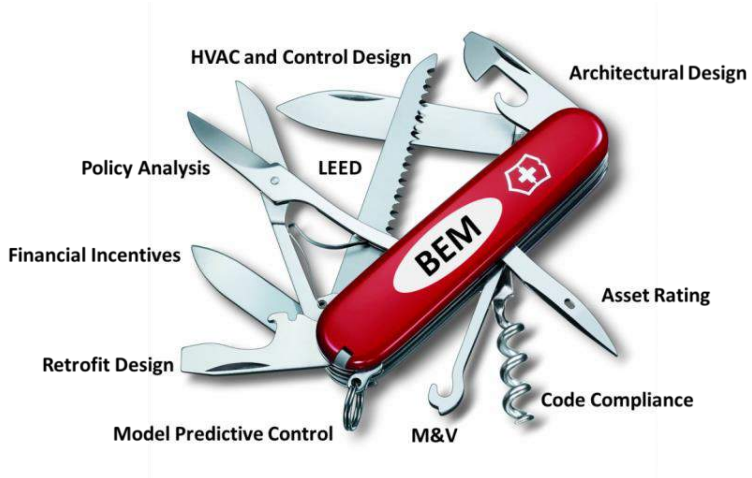


Figure 23: BEM applications in a nutshell [83]

The BEM software and energy renovation decisions – a sustainable approach

To ensure sustainability, energy renovation decisions need to consider other factors apart from energy performance improvements. Such factors include:

1) The life cycle financial or macro-economic feasibility aspects of applying a measure or a combination of energy renovation measures.
2) The social aspect and to what extent IEQ parameters such as thermal, acoustic, and visual comfort are positively impacted upon the introduction of a combination of energy renovation measures.
3) The environmental aspect (refer to Section 3), that is the life cycle environmental impact of a measure or combination of energy renovation measures. One concept is to identify to what extent the operational energy savings brought about by the energy retrofit measures compensate for the embodied energy used to manufacture, transport, and install the energy conservation measures themselves.

Importance of BEM software calibration for energy renovation projects

An EnergyPlus model, like all other models, is only a simplification of reality. A model will always behave differently to the real building even if all model input parameters are perfectly known. For energy renovation, to have confidence in the defined building energy model, one needs to ensure that for the base (as is) building scenario, in other words prior to the addition of energy conservation measures, the energy performance output of the model matches the metered energy consumption of the building as closely as possible using monthly resolution data or data at a higher resolution if available. The process of matching the simulation outputs of the building energy model with metered energy consumption data is known as calibration.

Calibration is a process that involves using measured data, such as utility bills, to establish a relationship between simulation outputs (such as simulated energy use) and independent variables (simulation input parameters). By adjusting the simulation parameter inputs, the goal is to find a set of inputs that closely align with the actual performance of the building.

Once the model calibration is validated, the modeller has increased confidence that energy performance improvements quantified from the EnergyPlus model via the application of energy efficiency measures will be more closely reflected. However, it must be noted that uncertainty is not fully solved using a calibrated energy model. Calibration is a complex and time-consuming process, which typically involves several input parameters that must be calibrated using a relatively limited amount of measured data. Thus, because of combinatorial complexity, calibration is an underdetermined system in which there can exist many unique models working within a tolerable margin of error [83].

Despite this complexity, how well a model is calibrated is usually evaluated and determined using statistical metrics in the form of the normalised mean bias error (NMBE) and the coefficient of variance of the root mean square error [CV(RMSE)] described in ASHRAE [83]

If one uses monthly energy consumption data from energy bills for calibration, to achieve monthly calibration, the resulting normalised mean bias error (NMBE) should be lower than 5% and the coefficient of variation of the root of the mean square error cv (RMSE) should be lower than 15 % [83]. These statistics are defined by Eq. 1 and 2.

$$\text{NMBE}=\frac{\sum (V_{bill}-V_{mod})}{(N-1)\ \overline{V}_{bill}}\cdot 100 \qquad \text{(Equation 1)}$$

$$\text{cv(RMSE)}=\frac{\sqrt{\frac{\sum (V_{bill}-V_{mod})^2}{(N-1)}}}{\overline{V}_{bill}}\cdot 100 \qquad \text{(Equation 2)}$$

Where V_{bill} is the monthly energy consumption data from the utility bills, V_{mod} are the simulated monthly energy use output, and $\overline{V}_{bill}$ is the average value of the monthly bills data under consideration. $cv(RMSE)$ shows the ability of the model to recreate the data, and the NMBE tests the bias of the predicted output versus the reference.

A schematic illustrating the process to calibrate unknown parameters in the model is depicted in Figure 24.

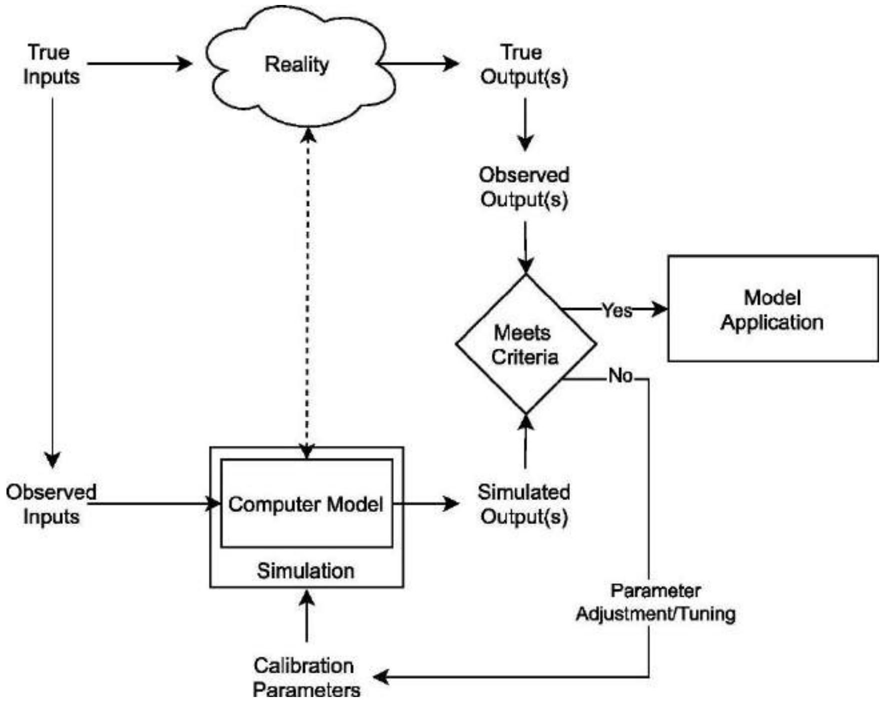


Figure 24: A schematic illustrating the calibration process [123]

Case-study Methodology

The approach adopted to study the energy performance of the HSBC case study building can be divided into the following steps:

1) Data collection, analysis, and statistical modelling.
2) Weather file construction.
3) Building energy model set-up.
4) Building energy model calibration and validation.
5) Modification of the geometry and zoning for the building energy model to reflect the proposed refurbished building.
6) Cost-optimal analysis:
    a. Measures and Packages: identification of packages of efficiency/renewable energy measures to improve the energy performance of the building.
    b. Primary energy calculation in kWh/m²/annum for each package of measures.
    c. Global cost calculation for each package of measures as stipulated in the EPBD guidelines [11] .

d. Consideration is given to the different discount rates and fuel price development scenarios/sensitivities. Calculations should also reflect a financial and macroeconomic perspective, where the latter also considers the cost of operational carbon emissions.
e. Cost-optimal analysis that considers global cost (€/m2) versus primary energy (kWh/m2.annum) plots are plotted for the different discount rates, price development and economic perspectives considered. The cost-optimal energy performance is derived from these plots. The measures falling within the cost-optimal energy performance range(s) also require to be analysed.

Stakeholders are encouraged to consult the ALDREN [84] project, a Horizon 2020 initiative, for a comprehensive framework for addressing state-of-the-art deep energy renovation and the voluntary energy performance certificate process for commercial buildings, such as offices and hotels. This framework encompasses various sustainable, risk, and economic aspects of the project. The authors believe that the ALDREN approach is the most effective method for retrofitting buildings and achieving the energy renovation targets outlined in the Green Deal [85] and the Renovation Wave for Europe [86] in practice.

The ALDREN project consists of four modules:

- ALDREN energy rating and targets
- Energy verification
- A health and well-being assessment protocol
- Cost, value, and risk

In addition, the two reporting tools are the:

- European Voluntary Certificate (EVC).
- Building Renovation Passport (BRP).

Due to time constraints, missing building characterisation and energy performance data, as detailed below, as well as financial limitations, the full ALDREN process could not be implemented for the case-study building. However, the process implemented for the case study touches upon important elements of the ALDREN project. These include the use of calibrated building energy models versus asset rating models. Such calibration allows one to derive energy ratings and targets that are more aligned with the actual operational energy performance of the building. The importance of such calibration for benchmarking is also highlighted in other EPC EU projects, including EPC RECAST [87], X-tendo [88], and U-CERT [89]. Furthermore, operational energy benchmarks for this case-study will be devised in line with the EPBD cost-optimal methodology [11] which considers the global life cycle costs of the different energy renovation measures under study from both a financial and macroeconomic perspective. In addition, the case study offers practical and statistical approaches to address challenges related to limited or missing data.

The ALDREN process emphasises the importance of voluntary environmental assessments and labels, such as the Building Research Establishment’s Environmental Assessment Method (BREEAM) and the U.S. Green Building Council’s (USGBC) Leadership in Energy and Environmental Design (LEED) rating system for new construction. These assessments aim to enhance the environmental performance of buildings.

Since its first release, LEED has continued to evolve in prominence to include rating systems for existing buildings and entire neighbourhoods. The local market relies on voluntary building certification schemes which are mainly developed and used for commercial buildings. Public and private users rely primarily on the mandatory EPCs.

In the absence of financial incentives, the take up of a voluntary building certification scheme relies on the perceived benefits by the client. These benefits can include marketing advantage and improvements to building performance, which are demonstrated through a label showcasing the building’s sustainability and the credibility of its energy assessment.

It is important to highlight the significance of the health and well-being assessment protocol, known as ALDREN-TAIL, in the ALDREN project. This protocol is used to evaluate the IEQ of buildings undergoing deep renovation, both before and during the renovation process. Its main purpose is to ensure the comfort, health and well-being of occupants based on specific metrics. Meeting the comfort and IAQ criteria outlined in the protocol is crucial for a building to achieve the NZEB status in alignment with the EPBD. This emphasises the importance of considering the IEQ aspects during deep renovation projects to create a healthy and comfortable indoor environment for building occupants.

Given time and financial limitations, this IEQ/IAQ assessment, which requires extensive metering, was not carried out for the case-study building. The comfort and IAQ set points to calibrate the model were assumed based on literature standards, most importantly EN 16798-1 [8], and feedback from HSBC management.

Furthermore, to calibrate the building energy model and reduce uncertainties in the calibrated parameter values, stakeholders are recommended to use sub-metering operational consumption data for energy end-uses such as plug-loads, mechanical ventilation, space heating and cooling for office buildings. This metering is best done in conjunction with a detailed energy audit of the building according to ISO 50002:2014 [90]. This submetering data and detailed energy audit were not available for this case-study and building energy modelling was carried out using parameter values based on site-visits, literature, and feedback from HSBC management.

Step 1: Data collection, analysis, and statistical modelling

As detailed in the previous section, a significant amount of data is required to create an EnergyPlus model. This data includes weather information, building geometry, functionality details, envelope properties, HVAC equipment specifications, plug load data, occupancy patterns, and comfort schedules. Furthermore, to calibrate the model accurately, monthly operational energy consumption data is required.

Of further importance are data related to geometry, form, equipment, envelope properties and functionality (i.e., the floor area divided according to the space functionality of the building) and the way each zone in the building is conditioned. This data was obtained from site visits, 2D office floor plans, and further collaborated with the information provided by the management.

Regarding operational energy consumption, the management provided raw data in the form of ARMS bills for the years 2016 and 2020, which had to be translated into a spreadsheet format for analysis. For some months, the electricity consumption data on the ARMS bills was only provided as an estimated consumption value versus the actual consumption provided and thus was of limited use for calibration. Furthermore, energy consumption data was sometimes provided for two monthly or quarterly intervals, meaning that the consumption was not always available monthly. Additionally, the year 2020 had to be eliminated from the analysis due to different occupancy schedules caused by the COVID-19 situation, which was not representative of the typical building operation.

Given the missing and estimated data in the bills, to fill in the missing gaps in monthly consumption data, the Degree days modelling method (explained in [91]) was used to enable monthly consumption data to be modelled and generated for the year 2018, as it is the most complete year in which energy data was available. Degree days are a generated type of weather data, calculated from readings of outside air temperature. They are used extensively in calculations related to building energy consumption. Heating degree days indicate the energy consumption required for heating (in cold weather) while cooling degree days give an indication of the energy consumption required for cooling (in hot weather). For a month with no space heating requirements, the heating degree-days are zero in theory. The same also applies to space cooling, for which, for a month with no space cooling requirements, the cooling degree days are zero. The total degree days are the sum of the cooling and heating degree days. For a shoulder month, such as April, a well-insulated building with negligible heating or cooling needs will have zero total degree days in theory.

More technically, a degree-day is a measure of how often and by how many degrees the average daily temperature (the average of the daily maximum and minimum) for a location is above (for cooling) or below (for heating) a base temperature. The degree days for a month can be more accurately calculated by summing the degree-hours versus degree-days for a month. The degree-hours for the HSBC case study building were calculated using the outside hourly air temperature data obtained from MIA. The calculated degree days in a month are dependent on both the hourly outside temperatures and on the chosen base temperature. The base temperature is the temperature at which the building's internal heat gains counterbalance the heat losses to the outdoors so that the building requires neither heating nor cooling. The base temperature is building-specific and depends on many factors. The optimal base temperature is best determined mathematically by plotting energy consumption data for a given resolution and interval versus degree days (for the same resolution and interval) considering and varying multiple base temperatures for both cooling and heating until the best coefficient of determination (R^2) is achieved between the two variables.

For the case-study building, the available energy consumption data for the intervals shown in Table 10 was used for the Degree Day analysis. As can be seen, the energy consumption data for 2018 was not available by month as required for a monthly calibration analysis, and the objective of the degree-day analysis was to statistically approximate the energy consumption data for each month.

For each observation (measured energy consumption) or time interval (10 observations are shown in Table 10), the degree days for the corresponding time interval were calculated. The degree days were calculated for multiple cooling and heating degree day base temperature combinations using 2018 and 2019 hourly weather data from MIA. For each combination, the strength in the linear relationship between the energy consumption variable and the total degree days was calculated via correlation (Pearson correlation coefficient) until the largest value for the coefficient of determination (R^2) was obtained with a base temperature of 17°C for cooling and 19°C for heating.

Table 10: Metered monthly energy consumption data used in the degree-day analysis.

Start Date	End Date	Number of days	Electricity Consumption (kWh)
13/12/2017	22/01/2018	40	135417
23/01/2018	02/02/2018	10	43984
03/02/2018	15/03/2018	40	162802
16/03/2018	05/04/2018	20	77079
06/04/2018	10/05/2018	34	135417
11/05/2018	06/07/2018	56	282941
07/07/2018	12/09/2018	67	395749
13/09/2018	27/11/2018	75	328751
28/11/2018	25/01/2019	58	199763
26/01/2019	25/03/2019	59	202257

Figure 25 shows the Degree-day plot with the best R^2 (R=0.87), corresponding to a base temperature of 17 °C for cooling and 19 °C for heating. The intercept of the graph shows the energy consumption in kWh at zero-degree days.

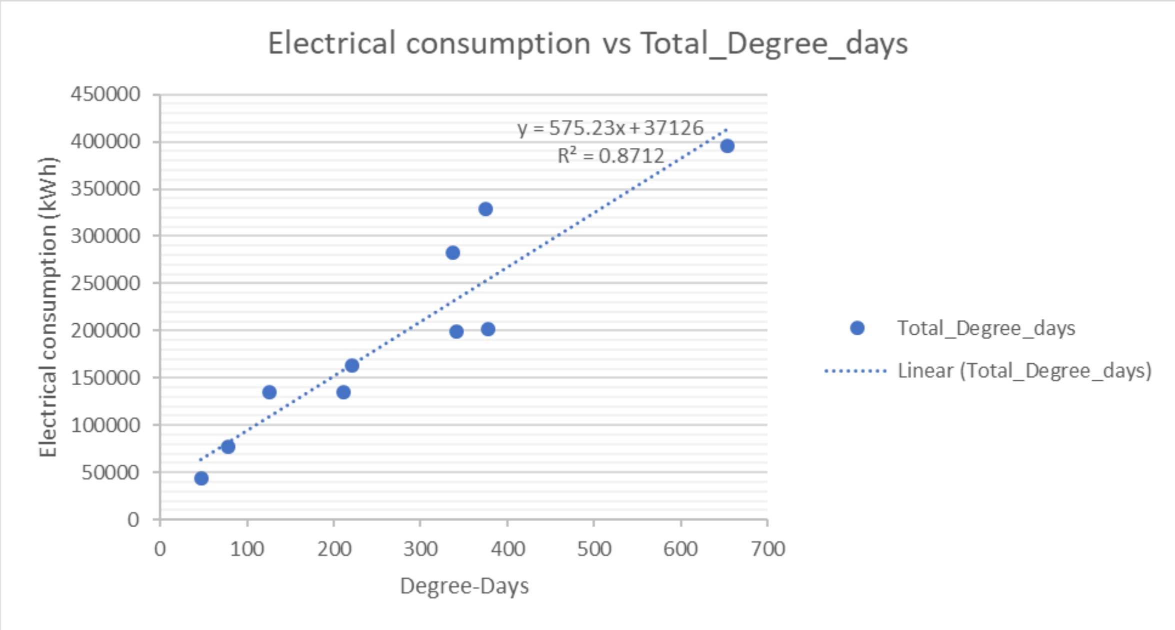


Figure 25: Degree-day plot (Electricity consumption versus degree-days) for the base temperature corresponding to the optimal R^2 (R^2=0.87). The optimal base temperatures are 17°C for cooling and 19°C for heating.

Based on the identified optimal base temperatures and the corresponding calculation of degree days for each month using 2018 hourly outside temperatures obtained from MIA, the monthly energy consumption data shown in Table 11 was estimated using the linear equation shown in *Figure 25*. This 2018 monthly data was used for building energy model calibration.

Table 11: Estimated monthly energy consumption per month for the year 2018

Month	Total degree days	2018 Calculated electrical consumption (kWh)	Cooling Degree days estimated from hourly weather data (base temp 17 °C)	Heating Degree days estimated from hourly weather data (base temp 19 °C)
Jan-18	154	125,975	2	153
Feb-18	175	137,767	0	175
Mar-18	133	113,751	11	122
Apr-18	109	99,730	40	69
May-18	116	103,637	91	25
Jun-18	202	153,275	202	0
Jul-18	313	217,293	313	0

Aug-18	309	214,848	309	0
Sep-18	255	183,714	255	0
Oct-18	143	119,192	138	4
Nov-18	98	93,523	55	43
Dec-18	144	120,175	4	141

Step 2: Weather file construction

The year 2018 was selected for the purpose of studying the building energy performance and calibrating the model. To input weather data into the EnergyPlus model and simulate the building's energy performance, a weather file for 2018 needed to be constructed in the EPW format. This format allows the input of weather data into the EnergyPlus model and the comparison of simulation results with the monthly operational consumption calculated for the building (as shown in Table 11).

To fulfil this objective, hourly weather data was obtained from MIA. This data consisted of various parameters, such as temperature, humidity, and solar radiation, which were all presented in CSV format. To convert the CSV files into the EPW format, the EnergyPlus open-source weather conversion tool [92]was utilised.

Important weather file parameters from this 2018 weather file are graphically summarised in Figure 26, Figure 27, and Figure 28 using software tools epwvis [93] and Climate Consultant [94].

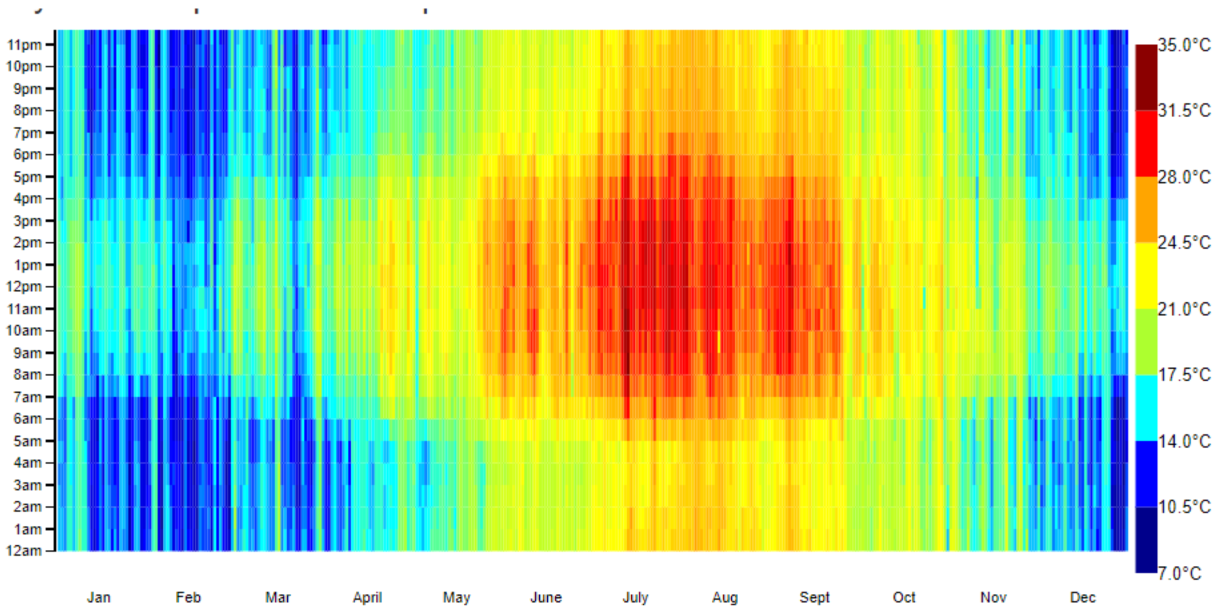


Figure 26: Dry bulb temperature flood plot generated from epwvis

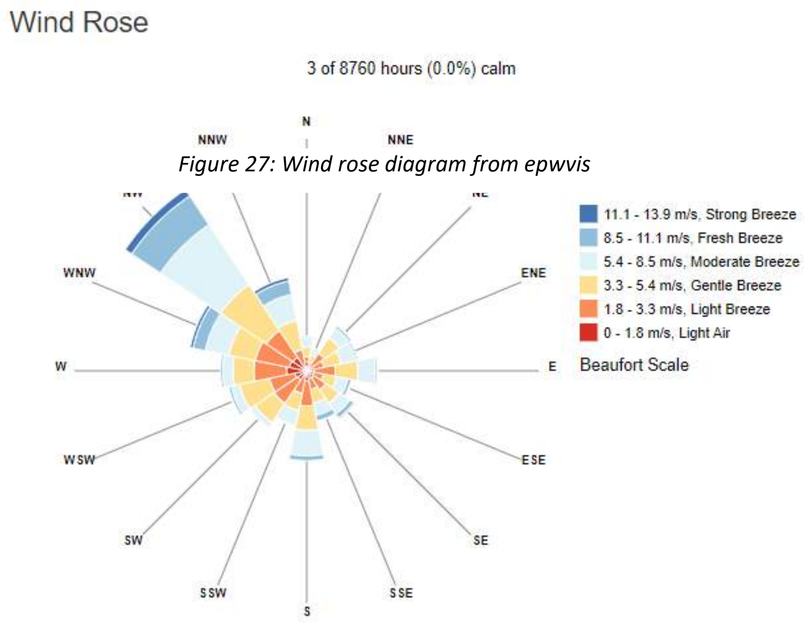


Figure 27: Wind rose diagram from epwvis

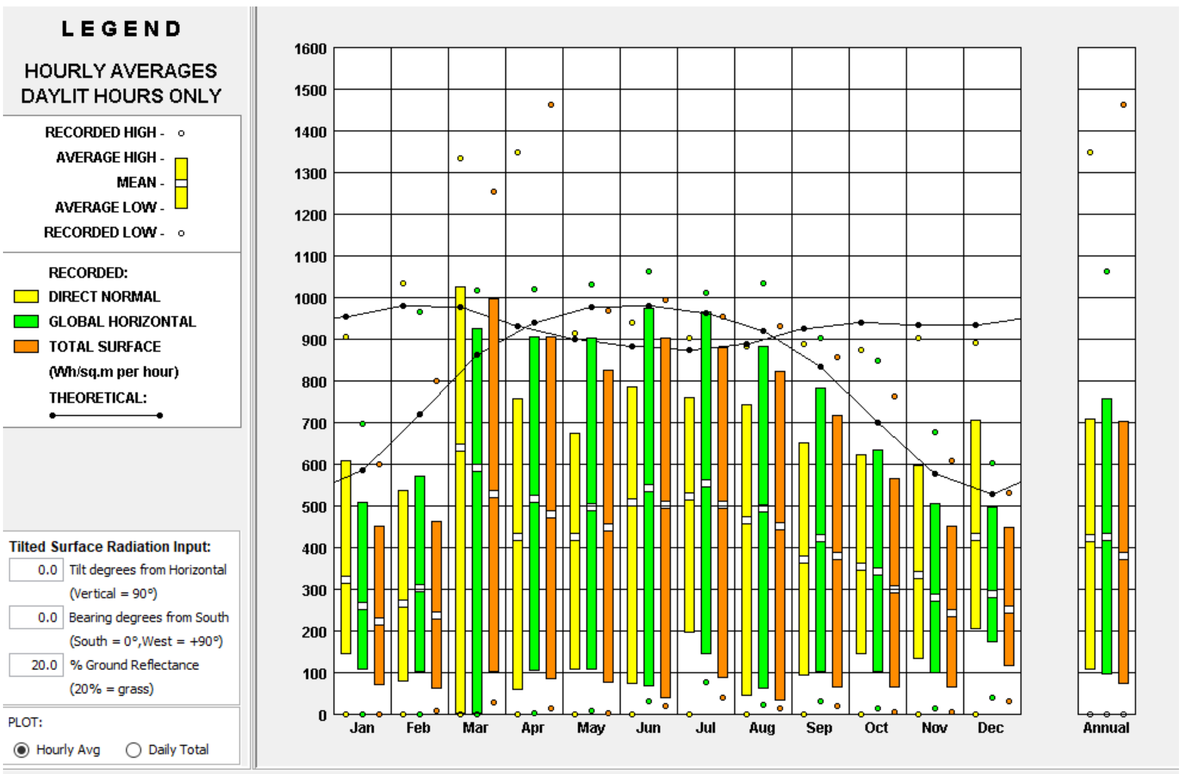


Figure 28 : Solar radiation monthly distribution generated from Climate Consultant

Step 3: Building energy model set-up

Once the data was collected, the building energy model was set-up in EnergyPlus by inputting all collected information for the geometry, envelope, operation, and HVAC equipment of the building. The geometry of the 3D building energy model is shown in *Figure 29* and the building is composed of four (4) blocks, block A to block D. The spaces in each block and floor were divided into different thermal zones according to the space functionalities and the equipment used to condition the spaces.

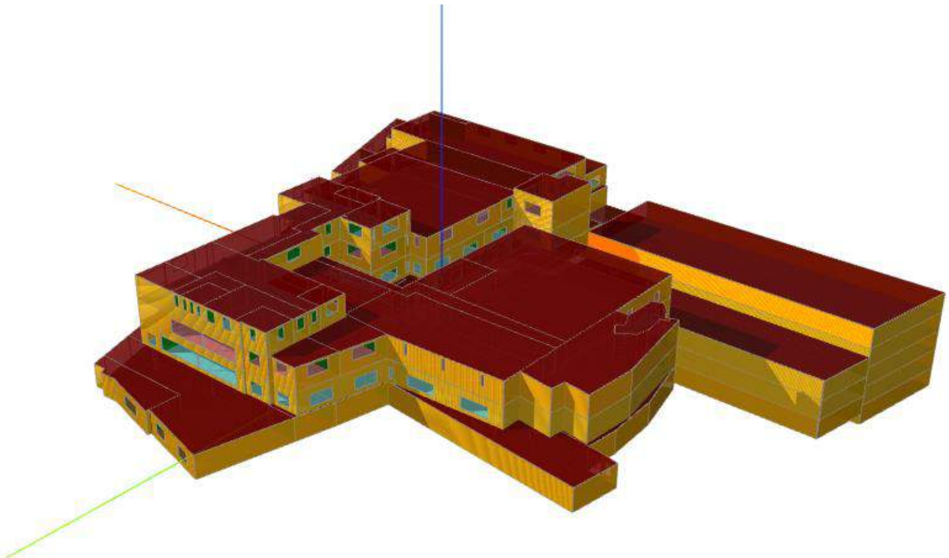


Figure 29: The geometry of the case-study building

Table 12 to *Table 15* depict the main building envelope, equipment, comfort, and operation/equipment schedule inputs for the building energy model case study. While some parameters may be taken as known, some parameters are uncertain, and a range of potential values based on literature and building management feedback were used to enable model calibration.

Table 12: The main building envelope parameter inputs to the model

Building envelope parameter	Parameter input	Description
Wall U-value	U= 2.1 W/m^{2}K	Concrete block construction
Roof U-value	U= 1.7 W/m^{2}K	Uninsulated roof with soffit
Glazing fenestration U-value	U= 6 W/m^{2}K	Single-glazed aluminium framing
Glazing SHGC	0.82	Clear glazing

Table 13: The main building equipment parameter inputs to the model

Building equipment	Parameter input	Description
HVAC main system	COP values (uncertain)	Old VRF system plus Dedicated Outside Air system (DOAS)
Lighting	Lighting power density 2.5 W/m^2/100 lux	Typical equipment efficiency for LED lighting
Office equipment	Plug load equipment 11.77 W/m^2	Typical plug load density from England EPC calculation methodology

Table 14 : Operation comfort set-points

Comfort set-points	Parameter input	Description
Space cooling temperature set-point for offices	Uncertain	Standard EN 16798-1 [8] and management feedback
Space heating temperature set-point for offices	Uncertain	Standard EN 16798-1[8] and management feedback
Mechanical ventilation	Air changes of 10 L/S/person	CIBSE guide A [95]requirement
Lighting	Office illuminance level = 500 lux	CIBSE guide A [95]and EN 16798[8]

Table 15: Main operation and equipment schedules

Schedules	Description
Office operation and HVAC schedule	Office spaces are considered occupied and cooled with 0.29 people per square meter, Offices are conditioned and occupied from 08:00 to 22.00 from Monday to Saturday. Circulation spaces are also considered space cooled and heated
Block occupancy	All blocks are considered occupied and conditioned, **block B is completely vacant**

Step 4: Building energy model calibration and calibration validation

To improve confidence in the building energy model, the model must be calibrated using the 2018 monthly calculated electrical energy consumption data shown in Table 11, and as generated from the degree-day analysis.

To enable this calibration, the uncertain parameters were varied simultaneously within a stipulated uncertainty range, allowing the model to generate multiple simulation runs, each run generating a data set with simulated monthly electricity consumption results. For each simulation run, the simulated monthly results were compared to the estimated 2018 monthly consumption shown in Table 11 and each time the $cv(RMSE)$ and NMBE calibration validation indicators discussed in the previous sections were calculated. This process was carried out until a combination of input parameters was found that minimised the values of the $cv(RMSE)$ and NMBE calibration indicators discussed above.

The simulation results for this scenario are shown in *Table 16* with resulting NMBEof 0.68% (calibration criteria < 5 %), $cv(RMSE)$ of 2.2 % (calibration criteria <15 %). Thus, the calibration was deemed successful according to ASHRAE standards [91] when considering the whole monthly building electrical energy consumption.

Furthermore, the results in *Table 16* and the corresponding scatter plot in Figure 30, which compare the monthly calculated electrical consumption from the degree days method and the simulated electrical consumption, show that given the minimal resulting discrepancies in monthly consumption patterns, the calibration was successful.

Table 16 : The calculated versus simulated monthly energy consumption for the year 2018 building energy modelling calibrated scenario

<table>
<tr><th>Month</th><th>2018 calculated electrical consumption using Degree days modelling (kWh)</th><th colspan="2">EnergyPlus Simulated energy consumption using the 2018 weather file</th></tr>
<tr><td>Jan-18</td><td>125,975</td><td colspan="2">107,227</td></tr>
<tr><td>Feb-18</td><td>137,767</td><td colspan="2">94,410</td></tr>
<tr><td>Mar-18</td><td>113,751</td><td colspan="2">110,433</td></tr>
<tr><td>Apr-18</td><td>99,730</td><td colspan="2">121,788</td></tr>
<tr><td>May-18</td><td>103,637</td><td colspan="2">141,794</td></tr>
<tr><td>Jun-18</td><td>153,275</td><td colspan="2">154,676</td></tr>
<tr><td>Jul-18</td><td>217,293</td><td colspan="2">204,574</td></tr>
<tr><td>Aug-18</td><td>214,848</td><td colspan="2">205,949</td></tr>
<tr><td>Sep-18</td><td>183,714</td><td colspan="2">178,530</td></tr>
<tr><td>Oct-18</td><td>119,192</td><td colspan="2">148,666</td></tr>
<tr><td colspan="2">Nov-18</td><td>93,523</td><td>119,065</td></tr>
<tr><td colspan="2">Dec-18</td><td>120,175</td><td>106,281</td></tr>
<tr><td colspan="2">Total (Annual)</td><td>1,682,880</td><td>1,693,393</td></tr>
</table>

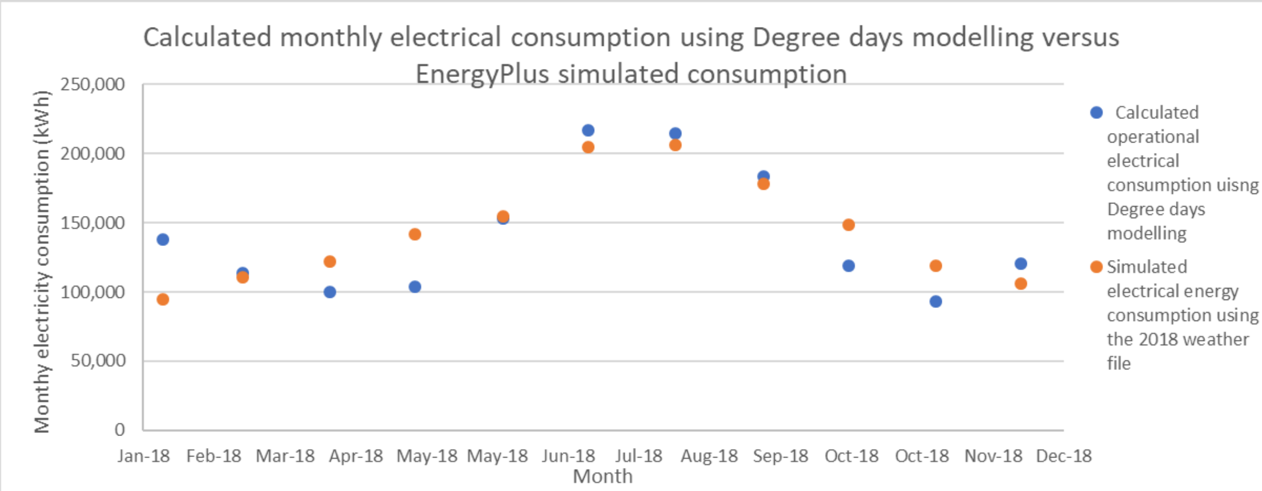


Figure 30: Calculated versus EnergyPlus simulated monthly electrical end-use for the year 2018

Energy Use (kWh/a)					Energy Generation (kWh/annum)	Delivered energy specified by source (kWh/a)			Primary Energy (kWh/a)
Space heating	Space cooling	Auxiliary Energy & plug loads	Lighting	DHW	PV's Energy Generation	Fossil fuel	Electricity	Others	Site to Primary energy conversion factor = 2
53,966	950,066	759,925	262,922	28,878	0	0	2,055,763	0	4,111,526

Step 5: Modification of the geometry and zoning for the building energy model to reflect the proposed refurbished building

The above calibrated (current) scenario is referred to as Scenario A. The current consumption (the as-is scenario) based on the year 2018 (with no PVs) is 1,693,393 kWh/annum (refer to *Table 16*).

In Scenario B, the building energy model geometry and zoning in terms of space functionalities were modified to reflect the post-refurbished scenario based on the proposed plans provided by HSBC. The calibrated values of the parameters for operation (comfort set-points, occupancy schedule etc.) and equipment efficiency from Scenario A were strictly retained in Scenario B. Furthermore, it is important to note that in Scenario B, building Block B is also occupied (unlike in Scenario A).

Table 17 summarises the building geometry characteristics for Scenario B.

The forecasted electrical consumption of the Scenario B reference scenario was calculated from the building energy model itself. The reference scenario is the scenario using the current systems, that is before the inclusion of any energy efficiency measures. As shown in Table 18, for Scenario B, given that Block B is now occupied, the forecasted site energy consumption increased to 2,055,763 kWh/annum or a 21% increase in consumption over the current consumption (Scenario A).

Table 17 also shows the site energy breakdown by end-use and the primary energy consumption using a site to primary energy conversion factor of 2. In addition, Table 19 shows the site and primary energy consumption normalised by the building's total useful floor area, which area excludes car parks.

Table 17: Scenario B building geometry characteristics

Exposed Wall area (m^2)	Exposed Roof area (m^2)	Fenestration area (m^2)	Total Floor area (m^2) including car parks	Total Floor area (m^2) excluding car parks	VRF Conditioned floor area including circulation spaces (m^2)
4,500	3,000	600	12,819	8,800	6,983

Space heating	Space cooling	Auxiliary Energy & plug loads	Lighting	DHW	PV's Energy Generation	Fossil fuel	Electricity	Others	Site to Primary energy conversion factor = 2
53,966	950,066	759,925	262,922	28,878	0	0	2,055,763	0	4,111,526

Table 18: Scenario B Annual energy end use

Energy Use (kWh/m²a)					Energy Generation (kWh/m²a)	Delivered energy specified by source (kWh/m²a)			Primary Energy (kWh/m²a)
Space heating	Space cooling	Auxiliary Energy & plug loads	Lighting	DHW	PV's Energy Generation	Fossil fuel	Electricity	Others	Site to Primary energy conversion factor = 2
6	107	86	30	3.3	0	0	233	0	467

Table 19: Breakdown of energy end-use normalised by total floor area (excluding carparks)

Step 6: Cost-optimal analysis

In step 6, the cost-optimal analysis is performed using the approach described in the EPBD cost-optimal method [11], [96]. In summary, various packages of measures will be applied to the Scenario B building energy model to improve its operational energy performance. Each package of measures will be costed using a (global) life cycle costing approach. The global cost (y-axis) versus primary energy (kWh/m^2/a) will be plotted considering the different packages of measures to identify the cost-optimal energy performance range of the building. The package(s) of measures that fall within this range will then be identified.

Step 6a: Identification of packages and measures

The following tables depict the specific energy efficiency measures applied to the building case-study to improve its operational energy performance. The measure upgrades and their variants are described both for the building envelope and for the equipment systems/components.

Building envelope measure upgrades

The specific measures for the building envelope include the application of wall insulation, the application of roof insulation, and the upgrade of fenestration (5 upgrade variants considered). These variants are shown in Table 20 to *Table 22: Fenestration specific measures upgrade variants* below.

Table 20: Wall specific measures upgrade options

Wall Options	U-value (W/m²K)	Proposed measure
Reference (as is)	As is wall U-Value (W/m²K) = 2.1 W/m²K	None
Upgrade 1	Upgrade of Wall U-value from 2.1 W/m²K to 0.5 W/m²K	Application of 5 cm XPS

Table 21: Roof specific measures upgrade options

Roof Options	U-value (W/m²K)	Proposed measure
Reference (as is)	As is roof U-Value (W/m²K) = 1.7 W/m²K	None
Upgrade 1	Upgrade of roof U-value from 1.7 W/m²K to 0.4 W/m²K	Application of 5/6 cm XPS

Table 22: Fenestration specific measures upgrade variants

Fenestration Options	Description	Proposed measure
Reference (as is)	As is - Single pane clear glazing with Aluminium frame	None
Upgrade 1	Single pane clear glazing with spectrally selective film (PR70) and aluminium frame	Application of spectrally selective film retaining current glazing
Upgrade 2	Double pane clear glazing with Aluminium frame	Replace single clear glazing with double pane clear glazing with Aluminium frame
Upgrade 3	Double pane clear glazing with PVC/thermal break frame	Replace single clear glazing with PVC/thermal break frame
Upgrade 4	Double pane clear glazing with spectrally selective film (PR70) and aluminium frame	Replace single clear glazing with double pane clear glazing with spectrally selective film (PR70) and aluminium frame
Upgrade 5	Double pane clear glazing with spectrally selective film (PR70) and PVC/thermal break frame	Replace single clear glazing with double pane clear glazing with spectrally selective film (PR70) and PVC/thermal break frame

Building energy systems and renewable energy upgrades

The specific measures for the building energy systems and renewable energy include upgrades to the VRF system and the installation of 52 kW_p of photovoltaic panels. These variants are shown in *Table 23* and *Table 24* below.

Table 23: HVAC specific measures upgrade

Space heating/cooling measure Options	Description	Proposed measure
Reference (as is)	Air cooled VRF calibrated scenario	None
Upgrade 1	Air-cooled VRF with double the COPs of the reference scenario	Replace VRF system with a system having double its efficiency

Table 24: *Options for specific measures upgrade variants for energy generated by solar renewable energy sources*

Renewable energy options	Description	Proposed measure
Reference (as is)	0 kW_p of PV panels	None
Upgrade 1	52 kWp of PV panels	Installation of PVs

Step 6b: (Net) Primary energy calculation in kWh/m²a for each package of measure

In this section, all measures shown in Table 20 to *Table 24* were combined to perform a full parametric analysis in EnergyPlus software with the building characterised using Scenario B geometry and operation. In total, the operational energy performance was studied for all 96 cases (package of measures). The 96 cases result by multiplying together the 2 wall options, the 2 roof options, the 6 fenestration options, the 2 HVAC options and the 2 renewable energy options shown in Table 20 to *Table 24*. The 96 cases including the operational energy performance results of the parametric analysis are shown in Appendix A. Appendix A also shows the percentage of energy performance improvement that results from each package of measures when compared to the reference scenario with no measures. The maximum potential operational energy saving possible is 30.5 % (refer to Variant 96). In Variant 96, the roof and wall are insulated, double-glazed PVC windows with the spectrally selective film is used, the VRF system is replaced with another VRF system having double the efficiency and 52 kWp of PVs are installed.

From Appendix A, it is shown that the replacement of the VRF system on its own produces 23 % of the energy performance improvement (Variant 25), and the addition of all envelope upgrades (wall, roof, fenestration upgrade 5) has the potential to improve the energy performance by a further 3.4 % (Variant 48). Furthermore, the installation of 52 kWp of PVs improves energy performance by a further 4.1 % (Variant 96).

If one had to compare the envelope measures without changing the VRF system, wall insulation has the potential to improve the energy performance by 1 % (Variant 13), roof insulation by 2.4 % (Variant 7) and fenestration upgrades by up to 1.77 % when fenestration upgrade 5 is applied (Variant 6). The simplest fenestration upgrade of installing a spectrally selective film (fenestration upgrade 1) provides an improvement of 1.45 % (Variant 4).

Step 6c: Calculation of the global cost for each package of measures

This section identifies the methodology used to calculate the Global Cost in €/m^2 for the package of measures shown in Appendix A in line with the EPBD guidelines [11]. The global cost calculations will be used to implement the cost-optimal analysis in Step 6d. All cost components and parameters affecting the global cost, including the discount rates and price developments used in the calculations are specified in this section. The EPBD guidelines [11], [96] require a global cost calculation both from a financial perspective and a macroeconomic perspective, where the macroeconomic perspective considers the cost of carbon emissions as detailed below.

Initial investment and maintenance/replacement costs considered for the applied measures

The initial investment cost, maintenance costs, replacement costs, and residual values cost components for each measure and used for the calculation of the global costs are shown in Appendix B. The costs are taken from 2021 cost-optimal studies for renovated office buildings in Malta and adjusted for inflation. The costs shown in Appendix B consider all applicable taxes including VAT, subsidies, and charges.

For this study, no learning rates have been assumed when any measures are replaced. The maintenance costs and lifetime of equipment have been calculated based on the guidelines of EN 15459: 2017 [97]. It must be noted that disposal costs were not considered for the calculation of global costs. The disposal costs are subjective (as for many of the measures chosen, no guidelines were included for disposal costs in EN 15459 [97]) and are heavily discounted given that they occur towards the end of the economic lifetime. According to the Regulation, the inclusion of disposal costs in the global cost calculation is not a requirement.

Calculation of global costs for the financial perspective for each package of measures

The global cost for each package of measures shown in Appendix A was calculated using the methodology described in EN 15459 [97]. This involves summing the different types of costs and applying a suitable discount factor, to discount their value to the first year as shown in equation 3 below. A 20-year calculation period was considered for all calculations.

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) \times R_d(i)) - V_{f,\tau}(j) \right] \quad \text{............eqn. (3)}$$

Where:

τ means the calculation period (taken as 20 years)

C_g (τ) means global cost (referred to starting year τ_0) over the calculation period

C_I means initial investment costs for measure or set of measures j

$C_{a,I\,(j)}$ mean annual cost during year i for measure or set of measures j

$V_{f,\tau}$ (j) means residual value of measure or set of measures j at the end of the calculation period (discounted to the starting year τ_0).

R_d (i) means discount factor for year i based on discount rate *r* to be calculated

The values in Appendix B were taken for the initial investment costs, annual maintenance costs and to calculate the residual value. The annual running operational cost was calculated using the operational energy consumption calculated for each package of measure in Appendix B and the electricity price development 1 values shown in Table 25. Price development 1 is based on the prices established by Government in the 2013 budget [32] and is the weighted average price per kWh for the first 5 bands including 5 % VAT. In this price development scenario, the price of electricity is kept constant throughout the 20-year calculation period as depicted in Table 25.

For the financial calculation, a central real discount rate of 4.5 % was applied. The 4.5 % represents the non-financial companies' lending rate as per statistics issued by the Central Bank of Malta for 2016 [98]. Further sensitivities were also carried out on both the electricity price developments and the discount rate. In total, the financial global cost was calculated for the following discount rate and price development configurations.

a. Discount rate (4.5 %), price development 1 for electricity
b. Lower Discount rate (3 %), price development 1 for electricity
c. Discount rate (4.5 %), price development 2 for electricity

Price development 2 (shown in Table 26) for electricity considers an average annual EU price increase of Euro 0.0057 per kWh following the trend in electricity development for non-household consumers between 2008 S1 and 2022 S1 as shown from the Eurostat website [99].

It must be noted that for the PV system, the financial incentives and feed-in tariff were not taken into consideration in cost calculations, as it was assumed that the electricity generated by the PV system was not exported to the grid but was used directly by the building.

The financial global costs for each package of measures are not shown in tables but will be visually depicted from the cost-optimal plots in Step 6d.

Table 25: Energy (electricity) costs for non-residential consumers considered in the calculations Price Development 1

Energy costs for non-residential consumers		Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Price development scenario																		
Electricity price dev. 1	€ cents/kWh		0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.1540	0.1540

Energy Costs for non-residential Consumers		Year	2039	2040	2041	2042	2043
Price development scenario							
Electricity price dev. 1	€ cents/kWh		0.1540	0.1540	0.1540	0.1540	0.1540

Table 26: Energy (electricity) costs for non-residential consumers considered in the calculations Price Development 2

Energy Costs for non-residential Consumers		Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
Price development scenario																		
Electricity price dev. 2	€ cents/kWh		0.154	0.160	0.165	0.171	0.177	0.183	0.188	0.194	0.200	0.205	0.211	0.217	0.222	0.228	0.234	0.240

Energy Costs for non-residential Consumers		Year	2039	2040	2041	2042	2043
Price development scenario							
Electricity price dev. 2	€ cents/kWh		0.245	0.251	0.257	0.262	0.268

Calculation of global costs for the macroeconomic perspective

The global cost for each package of measures shown in Appendix A was also calculated from a macroeconomic analysis. For the macroeconomic analysis, in addition to the costs included in the financial analysis, it is also necessary to include the cost of greenhouse gas emissions (Cc) as shown in the equation below.

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} (C_{a,i}(j) R_d(i) + C_{c,i}(j)) - V_{f,\tau}(j) \right]$$

The assumed cost of greenhouse gas emissions taken for the macroeconomic calculations are shown in Table 27, while Table 28 depicts the site energy to greenhouse gas emission conversion factors considered based on the year 2020 [100]. The assumed costs of greenhouse gas emissions have been taken to follow an average increase of Euro 14 /$tC0_2$ per annum as was the trend observed between the years 2008 to 2022 for the emission trading system [101].

For the macroeconomic analysis, it is to be noted that the VAT, subsidies, and charges must be removed. This means, that 18 % VAT was reduced from the costs shown in Appendix B, and 5 % VAT was reduced from the electricity prices shown in Table 25 and Table 26.

For the global cost macroeconomic calculation, a discount rate of 3 % was used as required by the regulation. A further sensitivity on the discount rate was carried out using a central discount rate for the macroeconomic calculation of 5 %, as stipulated by the Government Guidance Manual for Cost Benefit Analysis Appraisal in Malta (May 2013) [102] and as per Document of Cost-Benefit Analysis of Investment Projects Economic Appraisal Tool for Cohesion Policy 2014-2020 (2015) [103].

The macroeconomic global cost was calculated for the following discount rate and price development configurations.

For the macroeconomic calculation:

a. Price Development 1, discount rate of 3%
b. Price Development 2, higher discount rate of 5%

The calculation of the macroeconomic global costs for each package of measure is not shown in tables but will be visually depicted from the cost-optimal plots in Step 6d.

Table 27: Cost of greenhouse gas emissions up to 2050 considered for the macroeconomic analysis for this study [104]

Cost of Carbon	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038
€/TCO_2	70	84	98	112	126	140	154	168	182	196	210	224	238	252	266	280

Cost of Carbon	2039	2040	2041	2042	2043	
€/TCO_2	294	308	322	336	350	

Table 28: Site energy to $kgCO_2$ conversion data used for the macroeconomic analysis of this study

Emissions Data	
Electrical (site) energy to $kgCO_2$ conversion factor	0.414

Step 6d: Cost-optimal analysis (Global costs versus primary energy plots)

Based on the calculations of primary energy use (performed as described in Step 6b) and global costs (refer to Step 6c) associated with the different packages of measures (the packages of measures are shown in **Error! Reference source not found.**), graphs were plotted as global costs (y-axis: Euro/m² of u seful floor area) versus primary energy use (x-axis: kWh primary energy / m² useful floor area per annum).

For the HSBC building Scenario B, the cost optimum minimum energy performance requirements were determined from the graphs for the discount rate and price development configurations described is Step 6c for both the financial and macroeconomic analysis and considering the scenario with and without PVs (RES). The cost-optimal analysis was performed for the below 10 configurations/sensitivities in total:

For the financial calculation:

a. With RES - Discount rate (4.5 %), price development 1 for electricity
b. With RES – Lower Discount rate (3 %), price development 1 for electricity
c. With RES – Discount rate (4.5 %), price development 2 for electricity
d. No RES - Discount rate (4.5 %), price development 1 for electricity
e. No RES – Lower Discount rate (3 %), price development 1 for electricity
f. No RES – Discount rate (4.5 %), price development 2 for electricity

For the macroeconomic calculation:

a. With RES - Discount rate (3 %), price development 1 for electricity
b. With RES – higher discount rate (5 %), price development 1 for electricity
c. No RES – Discount rate (3 %), price development 1 for electricity
d. No RES – higher discount rate (5 %). price development 1 for electricity

For each of the 10 resulting plots (Figure 31 to Figure 40),that is one plot resulting from each of the above configuration/sensitivity, the cost-optimal point and cost-optimal range of primary energy were depicted . More specifically the cost-optimal range in this study was taken to constitute the packages of measures starting from cost-optimal to those that have a superior energy performance and lie within 2.5 % of the global cost of the cost-optimal package of measures. The packages of measures that fell within this cost-optimal range were marked as an orange box in the 10 plots and listed for each plot (Table 29 to Table 38) The packages of measures were analysed carefully for each of the 10 resulting plots. The red triangle in each plot shows the primary energy and global cost of the reference scenario (scenario prior to the application of energy efficiency measures) while the pink column in each table is the cost-optimal package of measures, i.e., the package of measures that gives the lowest global cost.

Financial calculation with RES - DR (4.5 %), price development 1

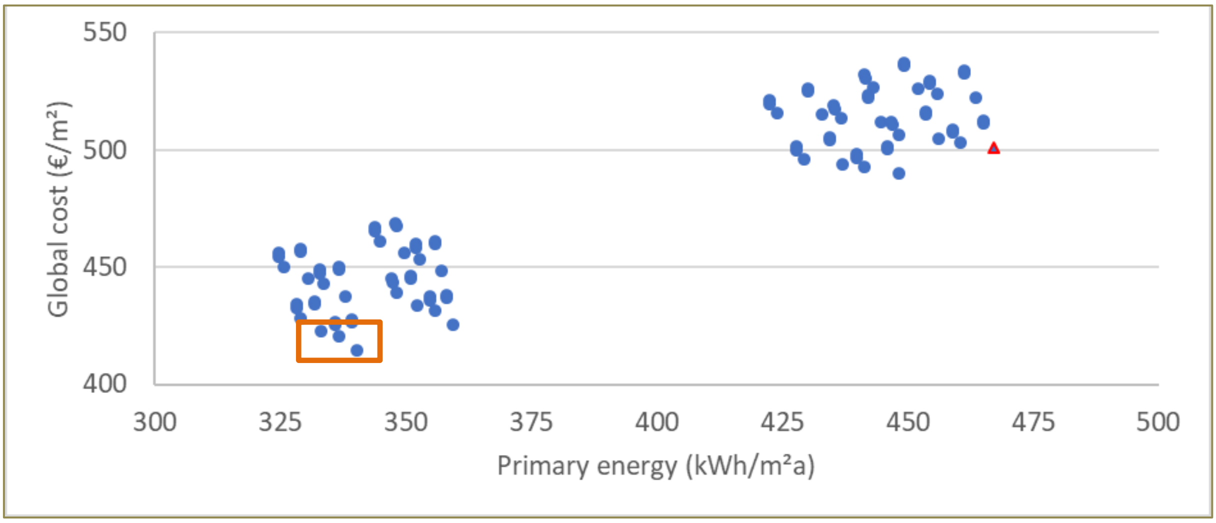


Figure 31: Global cost (€/m²) vs. Primary Energy (kWh/m²a) with RES- Price development 1 Discount Rate 4.5%

Table 29: Measures falling within the cost-optimal range (squared orange box) in Figure 31

Wall U-Value (W/m²K)	Roof U-Value (W/m²K)	Window Code	Space heating & cooling	Renewable energy (PVs) - % of roof area	Primary Energy (kWh/m²yr)	Financial calculation Global cost (€/m²)
2.10	1.70	Al_single	New_VRF	PVs	340.33	414.77
2.10	1.70	Al_single_film	New_VRF	PVs	336.64	420.55
2.10	0.40	Al_single	New_VRF	PVs	333.20	422.92

Financial calculation with RES - DR (3 %), price development 1

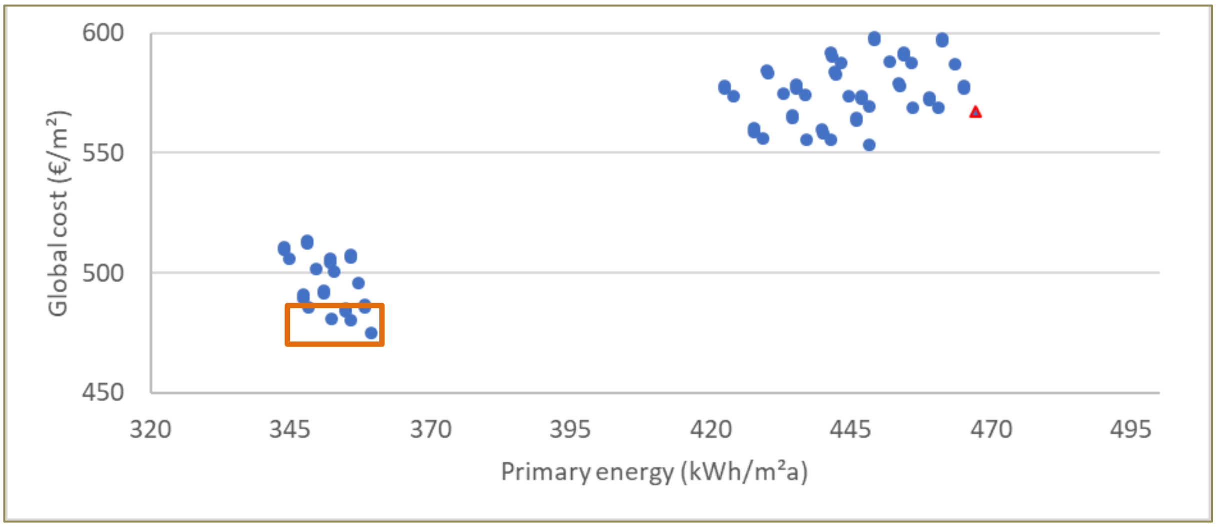


Figure 32: Global cost (€/m²) vs. Primary Energy (kWh/m²a) with RES - Price development 1 Discount Rate 3 %

Table 30: Measures falling within the cost-optimal range (squared orange box) in Figure 33

Wall U-Value (W/m²K)	Roof U-Value (W/m²K)	Window Code	Space heating & cooling	Renewable energy (PVs) - % of roof area	Primary Energy (kWh/m²yr)	Financial calculation Global cost (€/m²)
2.1	1.7	Al_single	New_VRF	PVs	340.32	461.28
2.1	1.7	Al_double	New_VRF	PVs	339.12	472.02
2.1	1.7	Al_single_film	New_VRF	PVs	336.63	466.53
2.1	1.7	Al_double_film	New_VRF	PVs	335.81	470.29
2.1	1.7	PVC_double_film	New_VRF	PVs	335.79	471.66
2.1	0.4	Al_single	New_VRF	PVs	333.20	467.58
2.1	0.4	Al_single_film	New_VRF	PVs	329.01	472.26

Financial calculation with RES - DR (4.5 %), price development 2

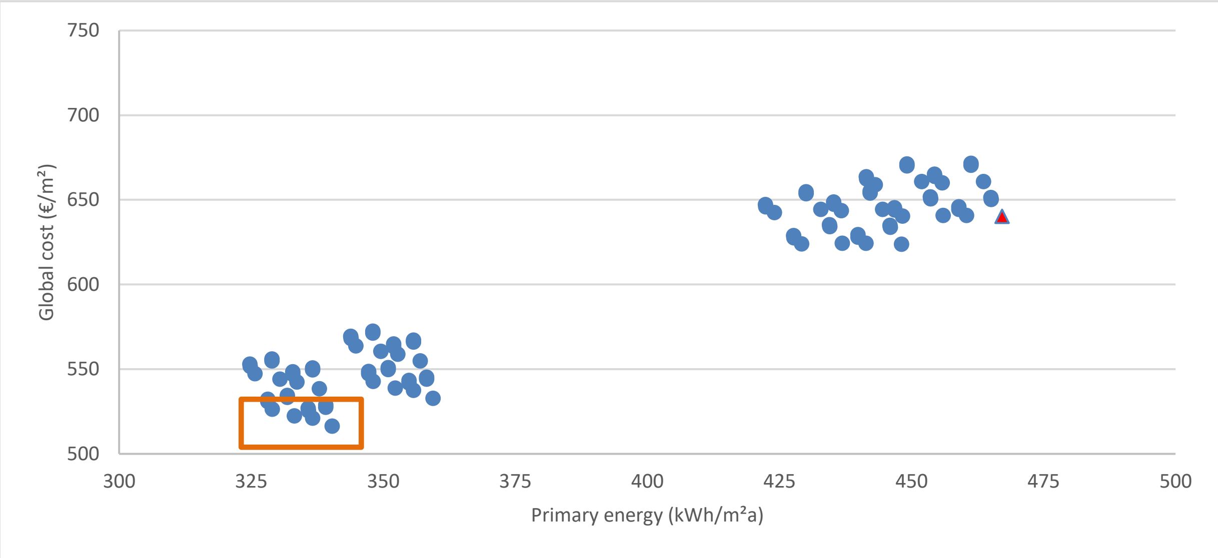


Figure 33: Global cost (€/m²) vs. Primary Energy (kWh/m²a) -financial calculation with RES - Price development 2 Discount Rate 4.5 %

Table 31 : Measures falling within the cost-optimal range (squared orange box) in Figure 33

Wall U-Value (W/m²K)	Roof U-Value (W/m²K)	Window Code	Space heating & cooling	Renewable energy (PVs) - % of roof area	Primary Energy (kWh/m²yr)	Financial calculation Global cost (€/m²)
2.1	1.7	Al_single	New_VRF	PVs	340.32	516.40
2.1	1.7	Al_double	New_VRF	PVs	339.12	527.65
2.1	1.7	PVC_double	New_VRF	PVs	339.10	528.80
2.1	1.7	Al_single_film	New_VRF	PVs	336.63	521.08
2.1	1.7	Al_double_film	New_VRF	PVs	335.81	525.53
2.1	1.7	PVC_double_film	New_VRF	PVs	335.79	526.97
2.1	0.4	Al_single	New_VRF	PVs	333.20	522.42
2.1	0.4	Al_single_film	New_VRF	PVs	329.01	526.46

Financial calculation without RES - DR (4.5 %), price development 1

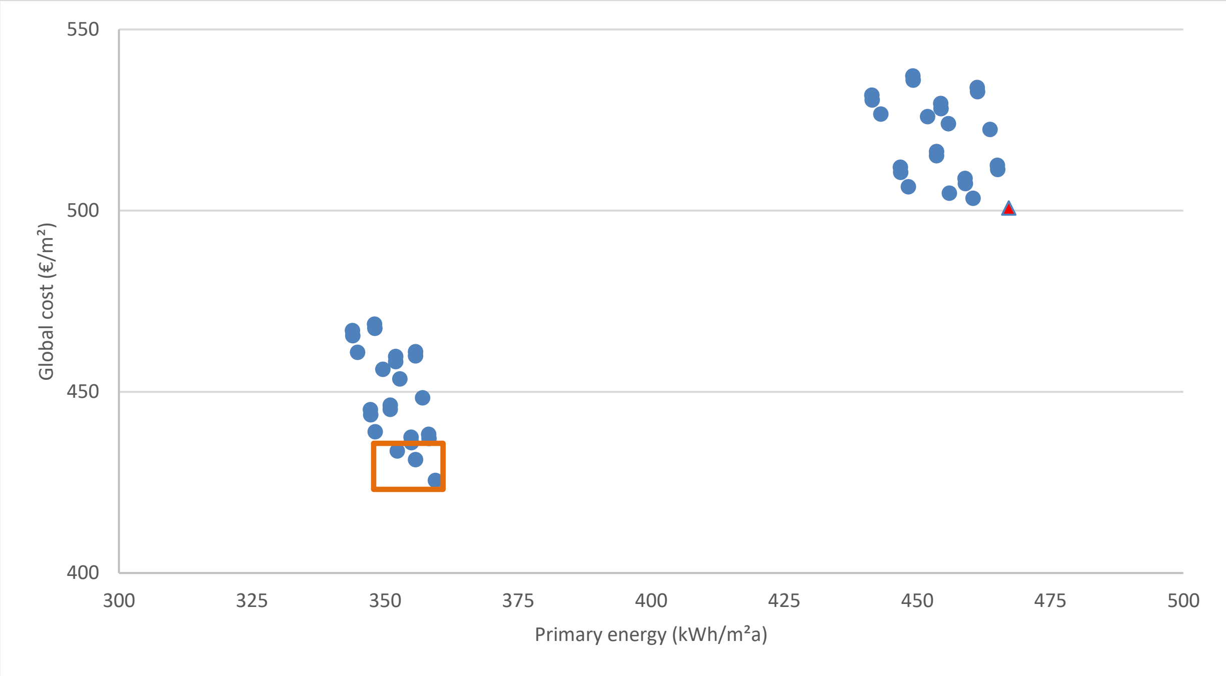


Figure 34: Global cost (€/m²) vs. Primary Energy (kWh/m²a) without RES financial calculation – Price development 1 Discount Rate 4.5%

Table 32: Measures falling within the cost-optimal range (squared orange box) in Figure 34

Wall U-Value (W/m²K)	Roof U-Value (W/m²K)	Window Code	Space heating & cooling	Renewable energy (PVs) - % of roof area	Primary Energy (kWh/m²yr)	Financial calculation Global cost (€/m²)
2.10	1.70	Al_single	New_VRF	No PVs	359.42	425.51
2.10	1.70	Al_single_film	New_VRF	No PVs	355.73	431.29
2.10	1.70	Al_double_film	New_VRF	No PVs	354.91	435.98
2.10	0.40	Al_single	New_VRF	No PVs	352.29	433.65

Financial calculation without RES - DR (3 %), price development 1

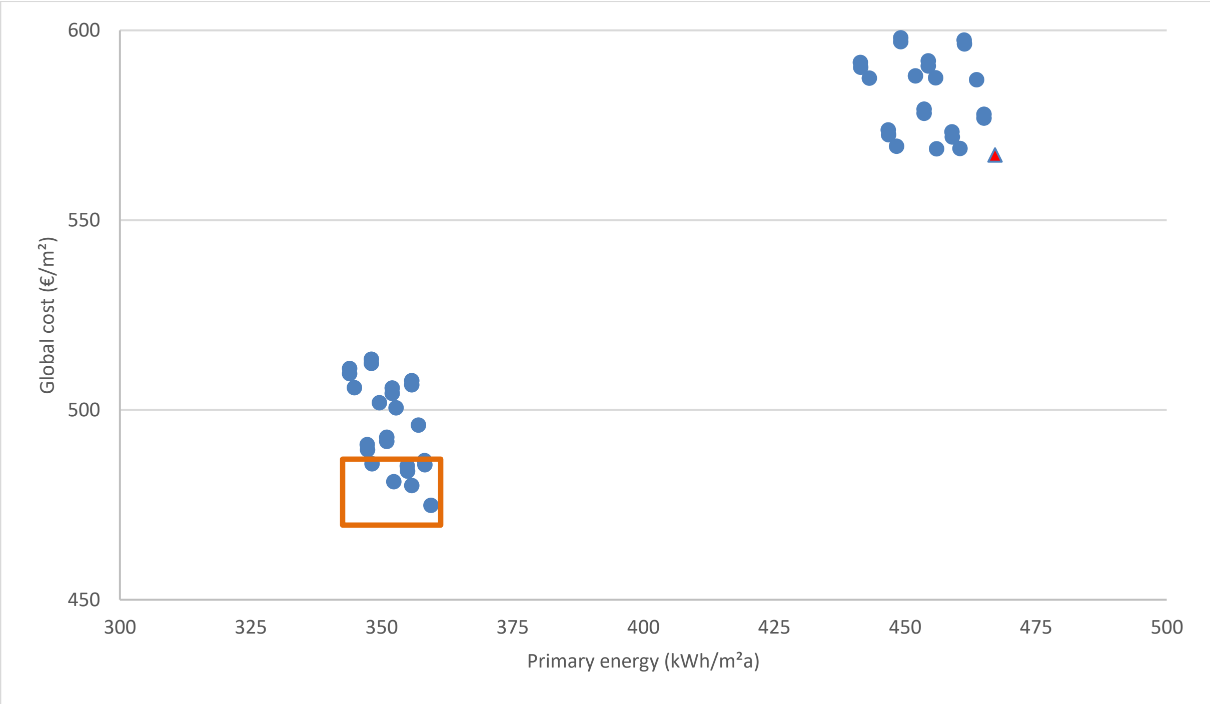


Figure 35: Global cost (€/m²) vs. Primary Energy (kWh/m²a) without RES financial calculation - Price development 1 Discount Rate 3 %

Table 33: Measures falling within the cost-optimal range (squared orange box) in Figure 35

Wall U-Value (W/m²K)	Roof U-Value (W/m²K)	Window Code	Space heating & cooling	Renewable energy (PVs) - % of roof area	Primary Energy (kWh/m²yr)	Financial calculation Global cost (€/m²)
2.1	1.7	Al_single	New_VRF	No PVs	359.41	474.79
2.1	1.7	Al_double	New_VRF	No PVs	358.21	485.54
2.1	1.7	Al_single_film	New_VRF	No PVs	355.72	480.05
2.1	1.7	Al_double_film	New_VRF	No PVs	354.90	483.81
2.1	1.7	PVC_double_film	New_VRF	No PVs	354.88	485.18
2.1	0.4	Al_single	New_VRF	No PVs	352.29	481.09
2.1	0.4	Al_single_film	New_VRF	No PVs	348.11	485.78

Financial calculation without RES - DR (4.5 %), price development 2

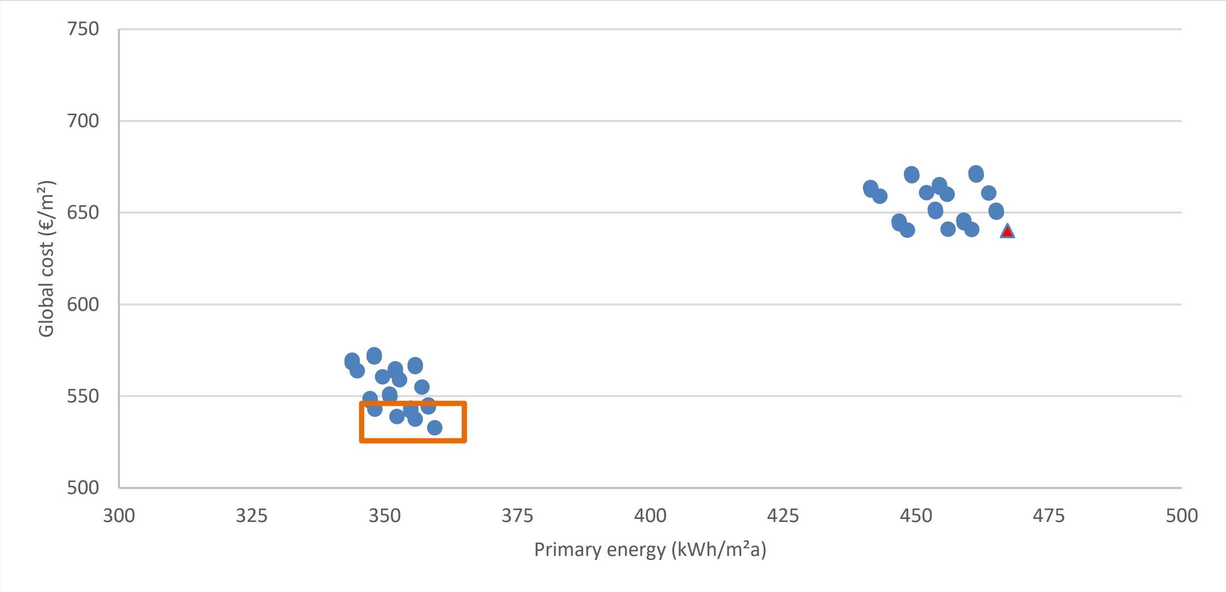


Figure 36: Global cost (€/m²) vs. Primary Energy (kWh/m²a) without RES financial calculation - Price development 2 Discount Rate 4.5 %

Table 34: Measures falling within the cost-optimal range (squared orange box) in Figure 36

Wall U-Value (W/m²K)	Roof U-Value (W/m²K)	Window Code	Space heating & cooling	Renewable energy (PVs) - % of roof area	Primary Energy (kWh/m²yr)	Financial calculation Global cost (€/m²)
2.1	1.7	Al_double	New_VRF	No PVs	358.22	544.08
2.1	1.7	PVC_double	New_VRF	No PVs	358.19	545.23
2.1	1.7	Al_single_film	New_VRF	No PVs	355.73	537.52
2.1	1.7	Al_double_film	New_VRF	No PVs	354.91	541.96
2.1	1.7	PVC_double_film	New_VRF	No PVs	354.89	543.40
2.1	0.4	Al_single	New_VRF	No PVs	352.29	538.85
2.1	0.4	Al_single_film	New_VRF	No PVs	348.11	542.89

Macroeconomic calculation with RES - DR (3 %)

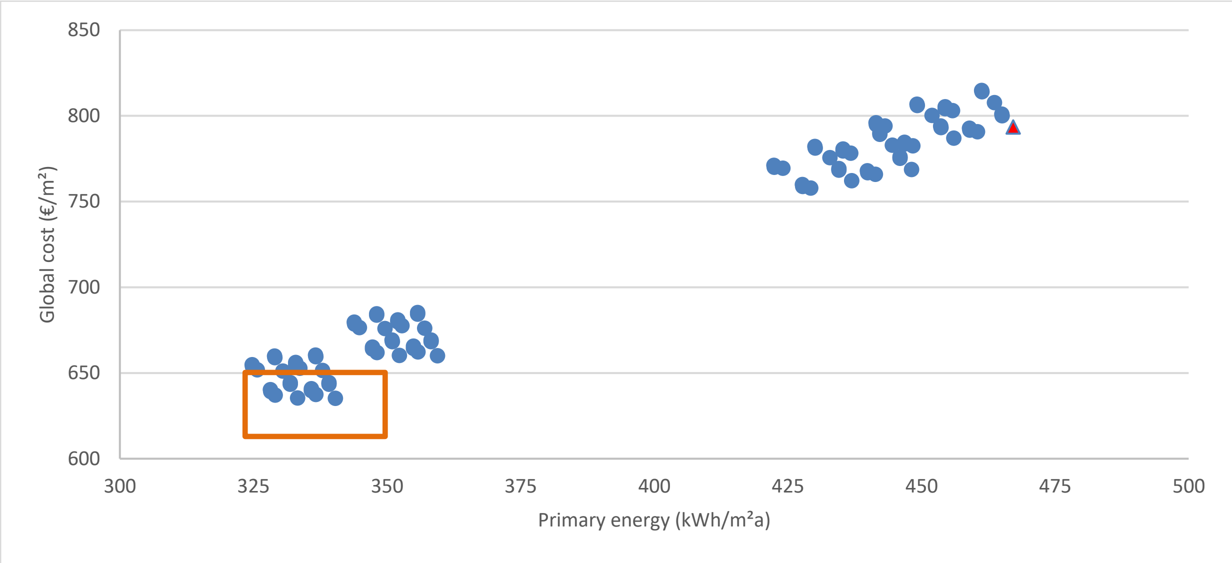


Figure 37: Global cost (€/m²) vs. Primary Energy (kWh/m²a) with RES Macroeconomic calculation - Discount Rate 3 %

Table 35: Measures falling within the cost-optimal range (squared orange box) in Figure 37

Wall U-Value (W/m²K)	Roof U-Value (W/m²K)	Window Code	Space heating & cooling	Renewable energy (PVs) - % of roof area	Primary Energy (kWh/m²yr)	Financial calculation Global cost (€/m²)
2.1	1.7	Al_single	New_VRF	PVs	340.32	635.15
2.1	1.7	Al_double	New_VRF	PVs	339.12	643.42
2.1	1.7	PVC_double	New_VRF	PVs	339.10	644.32
2.1	1.7	Al_single_film	New_VRF	PVs	336.64	637.54
2.1	1.7	Al_double_film	New_VRF	PVs	335.82	639.63
2.1	1.7	PVC_double_film	New_VRF	PVs	335.80	640.77
2.1	0.4	Al_single	New_VRF	PVs	333.20	635.48
2.1	0.4	Al_double	New_VRF	PVs	331.86	643.51
2.1	0.4	PVC_double	New_VRF	PVs	331.84	644.41
2.1	0.4	Al_single_film	New_VRF	PVs	329.02	637.04
2.1	0.4	Al_double_film	New_VRF	PVs	328.17	639.08
2.1	0.4	PVC_double_film	New_VRF	PVs	328.15	640.21
0.5	1.7	Al_single	New_VRF	PVs	337.92	651.39
0.5	1.7	Al_single_film	New_VRF	PVs	333.66	652.81
0.5	0.4	Al_single	New_VRF	PVs	330.47	651.17
0.5	0.4	Al_single_film	New_VRF	PVs	325.70	651.74
0.5	0.4	Al_double_film	New_VRF	PVs	324.78	653.66

Macroeconomic calculation with RES - DR (5 %)

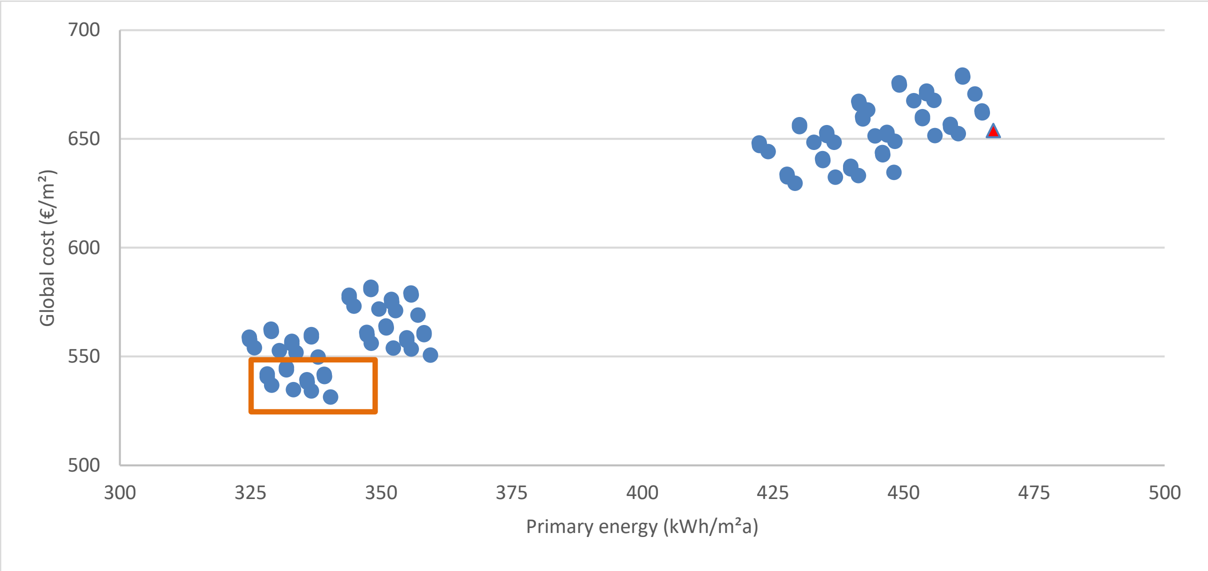


Figure 38 : Global cost (€/m²) vs. Primary Energy (kWh/m²a) without RES Macroeconomic Calculation Discount Rate 5%

Table 36: Measures falling within the cost-optimal range (squared orange box) in Figure 38

Wall U-Value (W/m²K)	Roof U-Value (W/m²K)	Window Code	Space heating & cooling	Renewable energy (PVs) - % of roof area	Primary Energy (kWh/m²yr)	Financial calculation Global cost (€/m²)
2.1	1.7	Al_single	New_VRF	PVs	340.32	531.44
2.1	1.7	Al_double	New_VRF	PVs	339.12	540.80
2.1	1.7	PVC_double	New_VRF	PVs	339.10	541.77
2.1	1.7	Al_single_film	New_VRF	PVs	336.63	534.22
2.1	1.7	Al_double_film	New_VRF	PVs	335.81	538.10
2.1	1.7	PVC_double_film	New_VRF	PVs	335.79	539.34
2.1	0.4	Al_single	New_VRF	PVs	333.20	534.75
2.1	0.4	Al_double	New_VRF	PVs	331.86	543.91
2.1	0.4	PVC_double	New_VRF	PVs	331.83	544.89
2.1	0.4	Al_single_film	New_VRF	PVs	329.01	536.85
2.1	0.4	Al_double_film	New_VRF	PVs	328.17	540.69
2.1	0.4	PVC_double_film	New_VRF	PVs	328.14	541.92

Macroeconomic calculation without RES - DR (3 %)

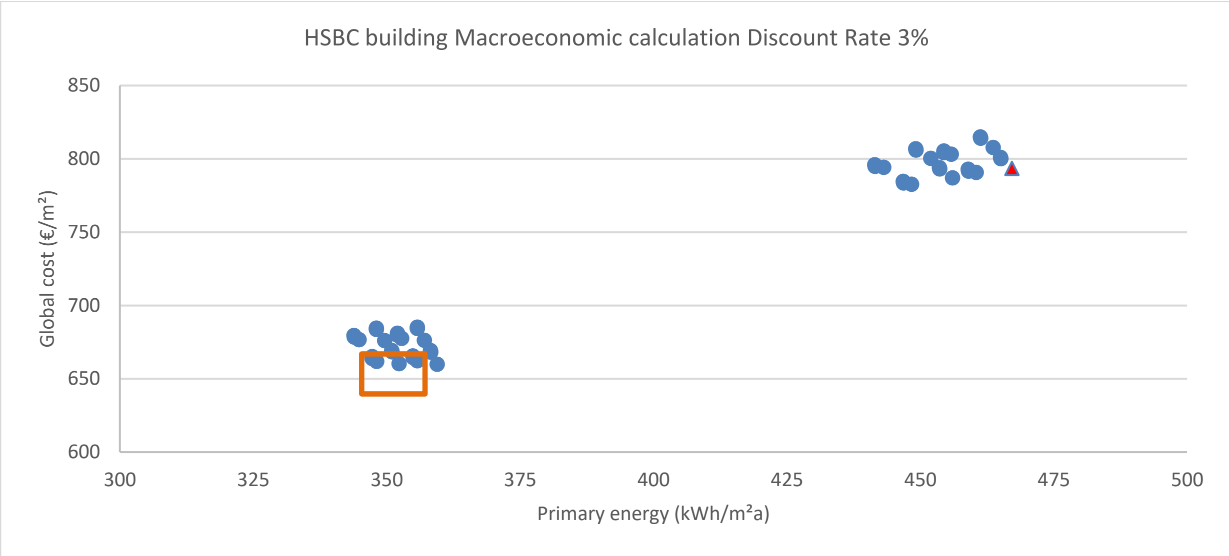


Figure 39 : Global cost (€/m²) vs. Primary Energy (kWh/m²a) without RES Macroeconomic Calculation Discount Rate 3%

Table 37: Measures falling within the cost-optimal range (squared orange box) in Figure 39

Wall U-Value (W/m²K)	Roof U-Value (W/m²K)	Window Code	Space heating & cooling	Renewable energy (PVs) - % of roof area	Primary Energy (kWh/m²yr)	Financial calculation Global cost (€/m²)
2.1	1.7	Al_single	New_VRF	No PVs	359.42	659.96
2.1	1.7	Al_double	New_VRF	No PVs	358.22	668.22
2.1	1.7	PVC_double	New_VRF	No PVs	358.19	669.12
2.1	1.7	Al_single_film	New_VRF	No PVs	355.73	662.34
2.1	1.7	Al_double_film	New_VRF	No PVs	354.91	664.43
2.1	1.7	PVC_double_film	New_VRF	No PVs	354.89	665.57
2.1	0.4	Al_single	New_VRF	No PVs	352.29	660.28
2.1	0.4	Al_double	New_VRF	No PVs	350.95	668.31
2.1	0.4	PVC_double	New_VRF	No PVs	350.93	669.21
2.1	0.4	Al_single_film	New_VRF	No PVs	348.11	661.84
2.1	0.4	Al_double_film	New_VRF	No PVs	347.26	663.88

Macroeconomic calculation without RES - DR (5 %)

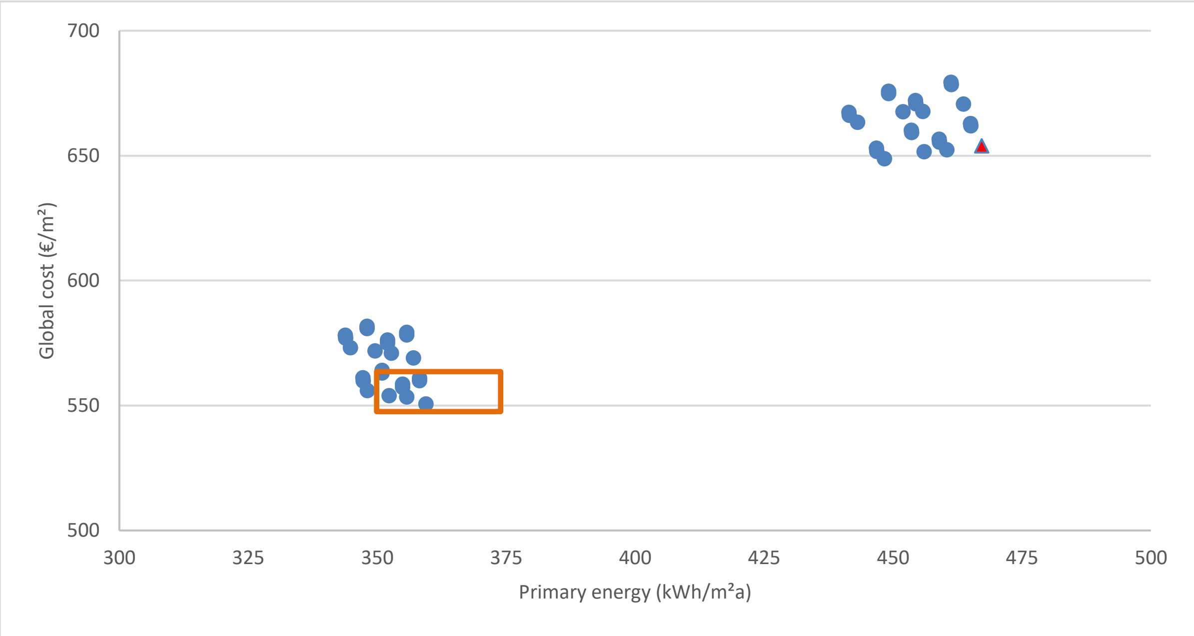


Figure 40: Global cost (€/m²) vs. Primary Energy (kWh/m²a) without RES Macroeconomic Calculation Discount Rate 5%

Table 38: Measures falling within the cost-optimal range (squared orange box) in Figure 40

Wall U-Value (W/m²K)	Roof U-Value (W/m²K)	Window Code	Space heating & cooling	Renewable energy (PVs) - % of roof area	Primary Energy (kWh/m²yr)	Financial calculation Global cost (€/m²)
2.1	1.7	Al_single	New_VRF	No PVs	359.41	550.64
2.1	1.7	Al_double	New_VRF	No PVs	358.21	560.00
2.1	1.7	PVC_double	New_VRF	No PVs	358.19	560.98
2.1	1.7	Al_single_film	New_VRF	No PVs	355.72	553.43
2.1	1.7	Al_double_film	New_VRF	No PVs	354.90	557.31
2.1	1.7	PVC_double_film	New_VRF	No PVs	354.88	558.54
2.1	0.4	Al_single	New_VRF	No PVs	352.29	553.95
2.1	0.4	Al_double	New_VRF	No PVs	350.95	563.11
2.1	0.4	Al_single_film	New_VRF	No PVs	348.11	556.05
2.1	0.4	Al_double_film	New_VRF	No PVs	347.26	559.89
2.1	0.4	PVC_double_film	New_VRF	No PVs	347.23	561.12

Discussion on Cost-optimal analysis

To aid the discussion, a summary of the results from the cost-optimal analysis (refer to Figure 31 to Figure 40 and Table 29 to Table 38) is provided in Table 39. As shown from the table, irrespective of the financial/macroeconomic sensitivity considered, the cost-optimal operational primary energy performance with PVs is 340 kWh/m^2/annum which represents a 27 % improvement in operational energy performance. This cost-optimal energy performance results when changing to a new VRF system with double the efficiency and installing 54 kW$_p$ of photovoltaic panels. When photovoltaics are not considered, the cost-optimal energy performance is 359 kWh/m^2/annum and is achievable by changing to a new VRF system having double the efficiency.

Given that Malta has a temperate climate, the building envelope measures have less impact on energy performance when compared to building energy systems and photovoltaics. This was shown in multiple studies including [14], [105], [106], [107], [108], [109], [110]. Thus, the building envelope measures are not found within the package of measures that achieve cost-optimal energy performance. However, when considering the cost-optimal energy performance range(s) versus the cost-optimal energy performance in Table 39, the installation of spectrally selective window film and the application of roof insulation fall within the cost-optimal energy performance range of the financial analysis calculations. Therefore, the application of these building envelope measures only has a small increase of approximately 2.5 % on the cost-optimal financial global cost. Furthermore, as shown in Table 39, from a macroeconomic perspective that also considers the cost of operational carbon emissions, the application of wall insulation and double-glazed aluminium fenestration with spectrally selective coating also feature within the cost-optimal range together with roof insulation. The application of all these measures presents only a small increase of approximately 2.5 % on the cost-optimal macroeconomic global cost.

Furthermore, the application of building envelope measures also has many non-financial benefits including improvements in thermal, visual (reduced glare) and acoustic comfort, while also reducing the peak space heating and cooling loads. These benefits have not been quantified in the cost-optimal exercise. Thus, given these benefits and only a minimal increase in the total global costs over 20 years, the building envelope measures, which include wall insulation, roof insulation, and double glazing with spectrally selective coating, should be considered in the energy refurbishment of the building, especially in the light of globally increasing energy costs. These measures are also required for the building to be compliant with the current Technical Document F [111]requirements. The application of building envelope measures also provides an additional energy performance improvement of more than 4 % over the cost-optimal scenario.

The implementation of energy efficiency measures including building envelope measures also enhances energy security in the light of global increased energy prices brought about by the Ukraine-Russia conflict. Such energy renovations contribute towards the EU meeting the 2050 zero carbon emission goals stipulated in the Green Deal [85] and the renovation targets stipulated in the EU Renovation Wave [86]. Additionally, these measures also promote a much-needed stimulus in the economy through the creation of green jobs following the COVID-19 pandemic.

Table 39: A summary of the results from the cost-optimal analysis for the different configurations/sensitivities.

Configuration/Sensitivity	Cost-optimal Primary Energy Performance (EP) (kWh/m² a)	Package of measures corresponding to cost-optimal EP	% EP improvement	Cost-optimal Primary Energy Performance (EP) (kWh/m² a)	Package of Measures falling within the cost-optimal EP range providing the best EP	% EP improvement considering best EP in range
Financial calculation with RES - DR (4.5 %), P. Dev. 1	340	New VRF, PVs	27	333-340	New VRF, PVs, roof insulation	28.7
Financial calculation with RES - DR (3 %), P. Dev. 1	340	New VRF, PVs	27	329-340	New VRF, PVs, fenestration (film application) and roof insulation	29.6
Financial calculation with RES - DR (4.5 %), P. Dev. 2	340	New VRF, PVs	27	329-340	New VRF, PVs, fenestration (film application) and roof insulation	29.6
Financial calculation without RES - DR (4.5 %), P. Dev. 1	359	New VRF	23	352-359	New VRF and roof insulation	24.6
Financial calculation without RES - DR (3 %), P. Dev. 1	359	New VRF	23	348-359	New VRF, fenestration (film application) and roof insulation	25.4
Financial calculation without RES - DR (4.5 %), P. Dev. 2	340	New VRF	23	348-359	New VRF, fenestration (film application) and roof insulation	25.4
Macroeconomic calculation with RES - DR (3 %)	340	New VRF, PVs	27	324-340	New VRF, PVs, fenestration (Al frame double glazed with film), wall insulation and roof insulation	30.6
Macroeconomic calculation with RES DR (5 %)	340	New VRF, PVs	27	328-340	New VRF, PVs, fenestration (Al frame double glazed with film) and roof insulation	29.8
Macroeconomic calculation without RES - DR (3 %)	359	New VRF	23	347-359	New VRF, fenestration (Al frame double-glazed with film) and roof insulation	25.4
Macroeconomic calculation without RES - DR (5 %)	359	New VRF	23	348-359	New VRF, fenestration (PVC frame double-glazed with film) and roof insulation	25.4

One must note several uncertainties and potential inaccuracies arise in the cost-optimal analysis performed. These uncertainties stem from, and include the following:

- Monthly electrical consumption data for one year to calibrate the current model (Block B assumed vacant) were estimated from the Degree days method. The Degree Day model was trained using the periods on the ARMS bills when actual consumption was available. This modelling approach was required given that the provided ARMS bills had many limitations, including many estimated versus actual consumption values and bills that were not issued at monthly intervals.

- Actual and future operation parameters of the building are highly uncertain and unknown. The parameter values after calibration are highly uncertain given the data limitations in the study and will never reflect the actual operating parameter values. The estimated parameter values used simply enable model calibration with operational energy consumption to reduce the energy performance gap. CIBSE has published a series of Technical Memoranda from TM61 to TM64, which provide detailed insights into operational building performance. For a comprehensive framework for undertaking measurement and verification of in-use building energy performance that also guides the development and validation of calibrated energy simulation models, CIBSE TM 63 [112]should be consulted.
- The effect of future climates on energy performance brought about by climate change was not considered for this study.
- No sub-metering data was provided, which adds many uncertainties to the calibration parameter values.
- An actual inventory of the building equipment with the required specifications was not available, which adds uncertainties to the calibrated values.
- Window-to-wall ratios and other building envelope/geometry parameters are estimated, as elevations were not comprehensively provided for both the current and the proposed refurbished layouts.
- It must also be emphasised that a detailed Energy Audit of the premises in line with ISO 50002:2014 standard and which non-SMEs are obliged to carry out by EU law was beyond the scope of the task to tackle any of the above uncertainties. The premises were simply chosen as a building energy model case-study. Such an audit is also required to identify potential improvements for plug-loads (office and bank machinery equipment) and mechanical ventilation which were not considered in the analysis.
- Furthermore, the derived energy performance benchmarks have not been optimised for comfort and indoor air quality and the benchmarks assume the operational set points and schedule as the calibrated scenario. Such an optimisation exercise requires a detailed energy audit to minimise uncertainties in the model as detailed above.

It should be noted that more advanced energy efficiency measures that have not been well-proven locally were not considered for this study. These include geothermal and Combined Heat and Power with cooling systems, sun pipe lighting and phase-change materials among others. Given that domestic hot water (DHW) constitutes only a small portion of the total energy use of the building, DHW measures such as solar water heating and DHW heat pumps were not analysed. Once the building's operational parameters are better known, energy savings from the replacement of the mechanical ventilation systems can also be quantified. Furthermore, the potential implementation of building energy management systems can also be costed and the improvement of energy performance from such systems quantified. This quantification can be done once these systems are designed based on the operational parameters of the building. Furthermore, only the current PV capacity in the building was considered in the analysis. The potential of the building-integrated PVs requires a detailed shading analysis while the potential identification of other locations where PV can be installed could not be determined at the time of request for information. This is due to outstanding permit requirements and the location of outdoor building services equipment layouts whose design was not yet finalised.

Building Certification Process

In addition to considering operational energy performance in buildings to meet EPBD requirements, companies seeking to meet ESG requirements should consider a broader spectrum of sustainable practices. Leadership in Energy and Environmental Design (LEED), a comprehensive certification framework for sustainable building design, offers a roadmap for addressing these aspects. Water efficiency, a crucial element of sustainability, is encouraged through LEED credits for reducing water consumption, utilizing recycled water, and installing water-efficient fixtures. LEED also promotes the use of sustainable materials and resources, awarding credits for incorporating recycled materials, locally sourced materials, and materials with low environmental impact. Furthermore, LEED emphasizes indoor environmental quality (IEQ), recognizing buildings that provide a healthy and comfortable indoor environment for occupants through good air quality, thermal comfort, and daylighting. LEED also encourages innovation by awarding credits for incorporating innovative sustainable design features. By addressing these aspects, companies can not only meet ESG requirements but also contribute to a more sustainable future.

It must be emphasised that LEED certification and building energy modelling (BEM) described in the previous section are not two separate concepts, but BEM can be used to support LEED certification in more than one way:

- LEED Energy and Atmosphere (EA) Credit 1: Optimize Energy Performance: BEM can be used to simulate the energy performance of the building and to compare it to the baseline energy performance requirements of ASHRAE 90.1. This can be used to demonstrate compliance with the LEED EA Credit 1.
- LEED EA Credit 2: On-Site Renewable Energy: BEM can be used to simulate the energy performance of the building with and without on-site renewable energy systems. This can be used to demonstrate that the building meets the requirements for the LEED EA Credit 2.
- LEED IEQ Credit 1: Enhanced Ventilation: BEM can be used to simulate the indoor air quality of the building. This can be used to demonstrate that the building meets the requirements for the LEED IEQ Credit 1.

- LEED IEQ Credit 7: Thermal Comfort: BEM can be used to simulate the thermal comfort of the building. This can be used to demonstrate that the building meets the requirements for the LEED IEQ Credit 7.
- The Green Building XML (GBXML) file format exported from a building energy model can be used to exchange data between building energy modelling software and life cycle assessment (LCA) software.

HSBC has committed to a sustainability vision for the Qormi Headquarters beyond operational energy performance. To this effect, the organisation has decided to carry out a refurbishment project to achieve a LEED v4 Building Interior Design and Construction certification. Initially HSBC decided to focus on Block B but later the organisation decided to include Blocks C and D. For this assignment, unlike the building energy modelling in the previous section, the assessment focused on Block B and the most significant retrofitting process.

During the last stages of the design phase of the project, a Value Engineering process was carried out, that modifies several aspects of the project with a potential implication in the LEED certification. The goal is to obtain LEED Interior Design and Construction (LEED ID+C) - GOLD certification. Throughout the assessment of the project and based on the potential of the Block B project, a scorecard was prepared (Refer to Figure 33) to assess the potential credits which could be obtained.

Project Overview

Main function	Office Building
Gross Floor Area (GFA)	5,055m^2 (56,563.8 sqft)
Number of Floors/levels:	Block B -> 3 levels (Ground, First, and Second floors) Block C -> 4 levels (Ground, First, Second, and Third floors) Block D -> 3 levels (Ground, First, and Second floors)
Peak Occupancy	769 total number of seats
Regular Occupants	TBC
Daily Visitors	TBC
Parking Spaces	TBC
Bicycle Parking Spaces	TBC
Bicycle Storage	52 storage spaces
Shower Facilities	7 shower spaces (according to plans)

Project Layout

Below one may find drawings of the layouts of the different blocks of the buildings. These are the blocks in their as is state and which will be retrofitted (ongoing finalisation works in Block B at time of documentation) to achieve LEED Gold Certification.

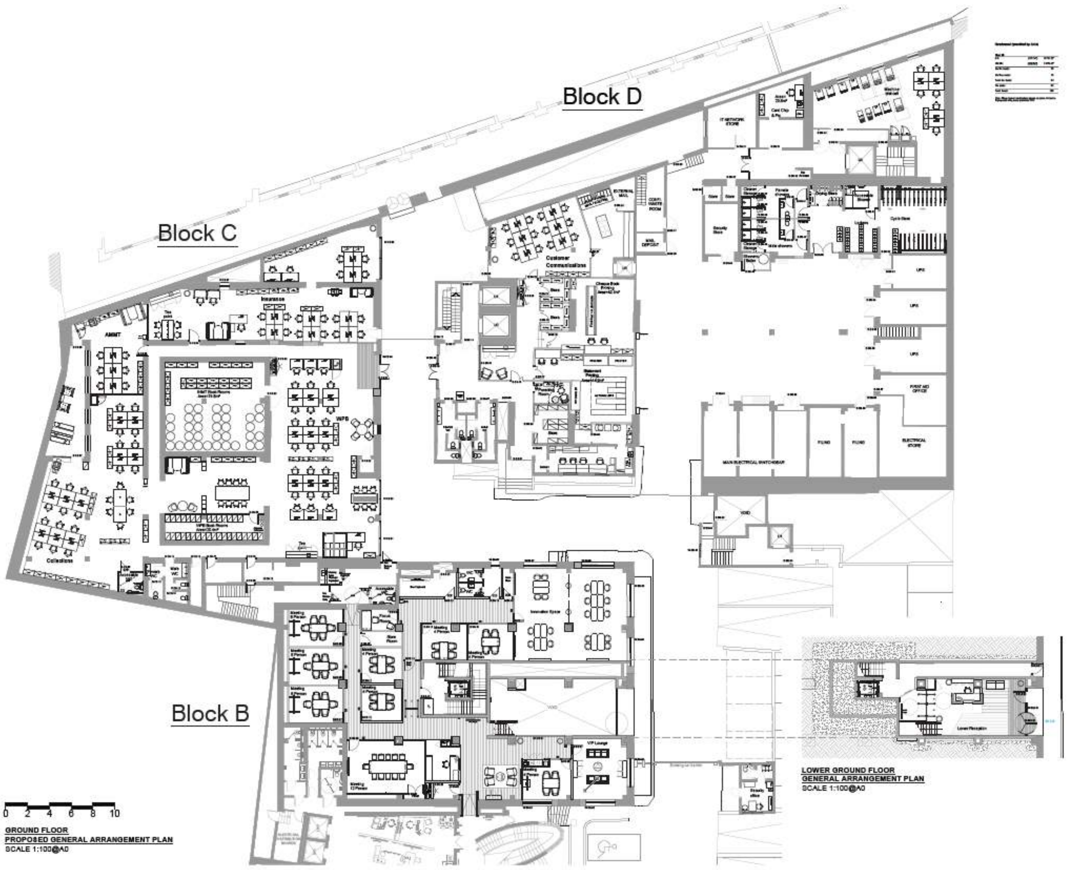


Figure 41: Ground Floor Plan

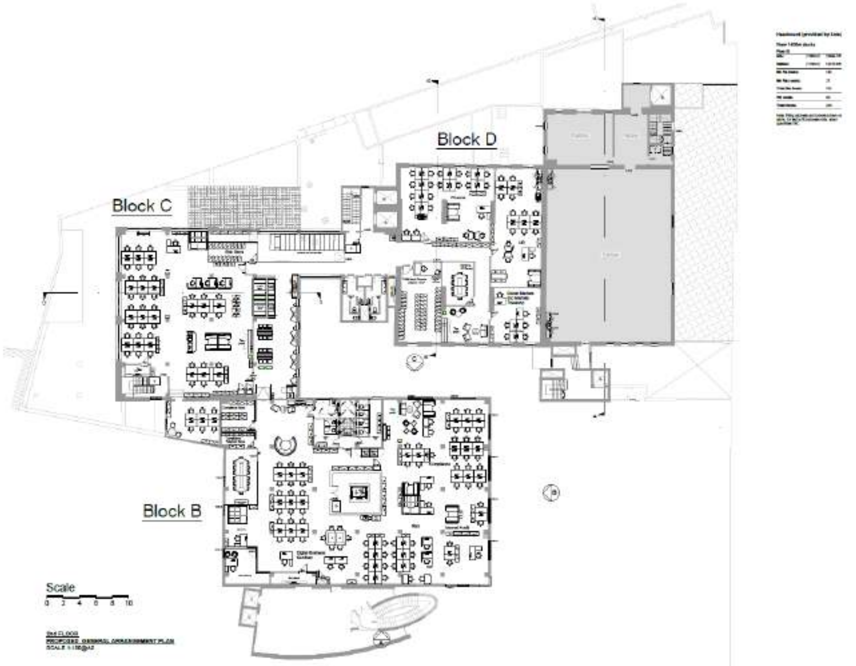


Figure 42: First Floor Plan

Figure 43: *Second Floor Plan*

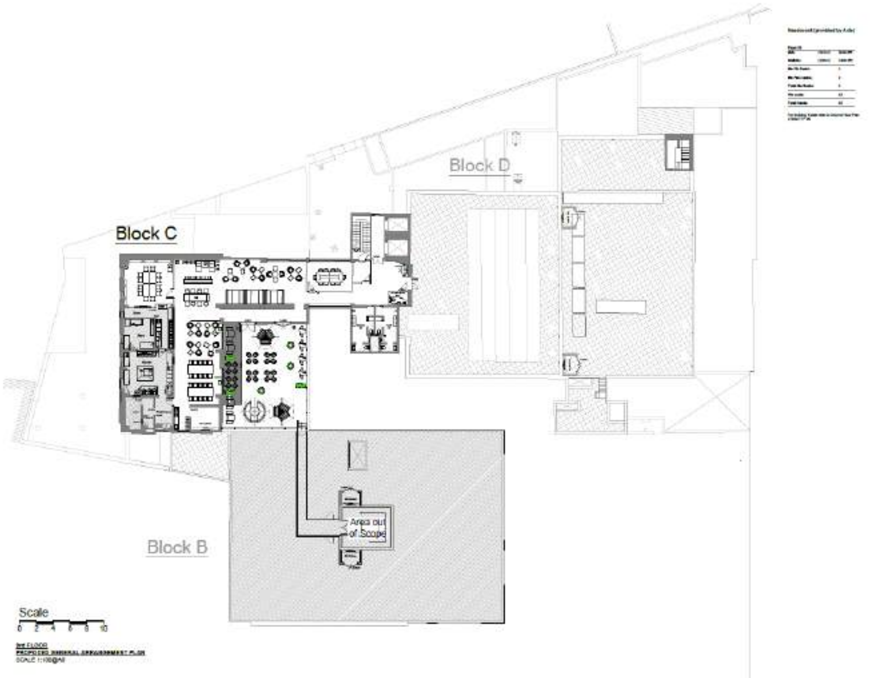


Figure 44: Third Floor Plan

LEED Scorecard

The scorecard is a preliminary study based on the location and the project documents received. The project has the potential to achieve a **GOLD level of certification.** This was discussed with HSBC during an opening meeting and was modified accordingly.

LEED v4 for ID+C: Commercial Interiors
Project Checklist

Project Name: HSBC Qormi
Date: 16/06/2023

Y	?	N			
2			Credit	Integrative Process	2
8	**7**	**3**		**Location and Transportation**	**18**
			Credit	LEED for Neighborhood Development Location	18
8			Credit	Surrounding Density and Diverse Uses	8
	6	1	Credit	Access to Quality Transit	7
	1		Credit	Bicycle Facilities	1
		2	Credit	Reduced Parking Footprint_4.1	2
8	**4**	**0**		**Water Efficiency**	**12**
Y			Prereq	Indoor Water Use Reduction	Required
8	4		Credit	Indoor Water Use Reduction	12
29	**4**	**5**		**Energy and Atmosphere**	**38**
Y			Prereq	Fundamental Commissioning and Verification	Required
Y			Prereq	Minimum Energy Performance	Required
Y			Prereq	Fundamental Refrigerant Management	Required
5			Credit	Enhanced Commissioning	5
20		5	Credit	Optimize Energy Performance	25
1	1		Credit	Advanced Energy Metering	2
3			Credit	Renewable Energy Production	3
	1		Credit	Enhanced Refrigerant Management	1
	2		Credit	Green Power and Carbon Offsets	2
3	**10**	**0**		**Materials and Resources**	**13**
Y			Prereq	Storage and Collection of Recyclables	Required
Y			Prereq	Construction and Demolition Waste Management Planning	Required
1			Credit	Long-Term Commitment	1
	4		Credit	Interiors Life-Cycle Impact Reduction_Design for flexibility + LCA_4.1	4
1	1			Environmental Product Declarations_4.1	2
	2		Credit	Sourcing of Raw Materials_4.1	2
	2		Credit	Material Ingredients_4.1	2
1	1		Credit	Construction and Demolition Waste Management	2
4	**9**	**4**		**Indoor Environmental Quality**	**17**
Y			Prereq	Minimum Indoor Air Quality Performance	Required
Y			Prereq	Environmental Tobacco Smoke Control	Required
2			Credit	Enhanced Indoor Air Quality Strategies	2
	3		Credit	Low-Emitting Materials_4.1	3
1			Credit	Construction Indoor Air Quality Management Plan	1
	2		Credit	Indoor Air Quality Assessment_4.1	2
	1		Credit	Thermal Comfort	1
1	1		Credit	Interior Lighting	2
		3	Credit	Daylight	3
		1	Credit	Quality Views	1
	2		Credit	Acoustic Performance	2
6	**0**	**0**		**Innovation**	**6**
1			Credit	Innovation	5
1			Credit	Innovation	1
1			Credit	Innovation	1
1			Credit	Exemplary Performance	1
1			Credit	Exemplary Performance	1
1			Credit	LEED Accredited Professional	1
2	**2**	**0**		**Regional Priority**	**4**
1			Credit	Regional Priority: Indoor Water Use Reduction (8 Points)	1
1			Credit	Regional Priority: Optimize Energy Performance (12 Points)	1
	1		Credit	Regional Priority: Interior life-cycle assessment	1
	1		Credit	Regional Priority: Indoor Air Quality Assessment	1
62	**36**	**12**		**TOTALS** Possible Points:	**110**

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80+

Figure 45: *Preliminary Scorecard Analysis*

The credits in Figure 45 are preliminary. Further information is required and needs to be assessed to provide a final target point scorecard. However, the assessment performed in Figure 45 shows that the estimated *certain* credits are equivalent to 62 and 36 uncertain credits. The number of points required for a Gold certification is 60-79, and therefore the results indicate a high likelihood of the project falling within this range.

Credit Analysis

This section analyses each category, detailing the score obtainable for each credit according to the strategy implemented and project specifications. The feasibility for each credit is indicated hereunder.

Design Credits

Integrative Process (2 points)

This credit is obtained by carrying out a simple simulation of the water and energy systems and preparing a report that is submitted as part of the documentation.

Location and Transportation

The credits which can be potentially obtained are the following:

- **Surrounding Density and Diverse Uses (8 points**) - The score for this section is mainly based on project location: access to public transport, facilities, and bicycle network.
- **Access to Quality Transit (6 points)** - This category merits further discussions with transportation authorities to assess the possibility of acquiring these points.
- **Bicycle Facilities (1 point)** - All requirements should be fulfilled (bike stations, showers and changing rooms), except the access to a bicycle network from the project (maximum distance 200m). This needs to be further analysed in the spirit of nearby Industrial and Commercial Estates.

Water Efficiency

Indoor Water Use Reduction (12 points) - The maximum score available would be obtained by installing the sanitary equipment aligned with LEED Specification. Additionally, it will be necessary to properly justify that rainwater is collected and reused for second class water.

Energy and Atmosphere

- **Commissioning (5 points):** Commissioning requirements should be followed as part of the LEED Basis of Design and aligned with the MEP Employer Requirements.
- **Energy Performance (20 points):** The amount of solar photovoltaics installed crucially impacts this category. An in-depth energy simulation exercise would need to be carried out to confirm the final number of points which may be attained in this credit. However, design features that would enable a better energy performance simulation include renewable energy capacity, external insulation, aperture replacement type, and roof insulation. The building energy modelling carried out during the initial process of WP2 supports the implementation of LEED and may be used during the detailed building energy modelling.
- **Energy metering (2 points):** Energy metering requirements and number of meters are detailed in LEED Basis of Design and aligned with the Mechanical, Electrical and Plumbing (MEP) Employer Requirements. It is important to install new, or use existing, tenant-level energy meters to provide tenant-level data representing total tenant energy consumption and demand.
- **Renewable energy production (3 points):** The estimated eligible capacity installation including the existing system will form an important part of the requirements which are needed to attain the highest possible score.
- **Refrigerant Management (1 point):** To ensure attainment of such credit, it is important to select heating, ventilating, air-conditioning, and refrigeration (HVAC&R) equipment that minimize the use of refrigerants that contribute towards ozone depletion and climate change. It is highly recommended to use refrigerants having a low ozone depletion potential, and a low global warming potential. It is also forbidden to use chlorofluorocarbon-based (CFC) refrigerants in new heating, ventilating, air-conditioning, and refrigeration (HVAC&R) systems. Also, HVAC systems should be optimized by avoiding equipment with a high refrigerant charge (Rc), to minimize refrigerant impact.
- **Green Power and Carbon Offsets (2points):** This is highly unlikely to be attained as Malta does not have a Carbon Offset market. This credit would require HSBC to:
- Engage in a contract for qualified resources that have come online since January 1, 2005, for a minimum of five years, to be delivered at least annually. The contract must specify the provision

of at least 50% (1 point) or 100% (2 points) of the project's energy from green power, carbon offsets, or renewable energy certificates (RECs).

- Purchase green power and RECs. RECs can only be used to mitigate the effects of Scope 2, electricity use.
- Purchase Carbon offsets to mitigate Scope 1 or Scope 2 emissions on a metric ton of carbon dioxide equivalent basis and must be Green-e Climate certified, or equivalent.
- The percentage of green power or offsets are determined based on the quantity of energy consumed, not the cost.

Materials and Resources

Long Term Commitment (1 point)

In the case of HSBC, since the owner of the property is HSBC and not a third-party owner, this credit is automatically acquired.

Interiors life cycle reduction (4 points)

This is classified in three categories:

- Interior Furniture and Non-structural Elements Reuse and/or furniture, separately or together, with a maximum reuse of 40% by cost. Hazardous materials that are remediated as a part of the project must be excluded from the calculation.
- Design for Flexibility and Disassembly therefore, incorporate interior elements that facilitate space flexibility and disassembly of components throughout the service life of the building interior.
- Building Interiors Life Cycle Assessment

Environmental Product Declarations (2 points)

- Option 1: Use at least **10 different permanently installed products** (1 point) sourced from at least three different manufacturers that meet one of the disclosure criteria.
- Option 2: Use at least **10 different permanently installed products** (1 point) sourced from at least three different manufacturers that have a compliant embodied carbon optimization report or action plan separate from the LCA or EPD.

Sourcing of Raw Materials (2 points)

Use products sourced from at least 3 different manufacturers that meet at least one of the responsible sourcing and extraction criteria below for at least 15% (1 point) or 30% (2 points), by cost, of the total value of permanently installed building products in the project.

Material Ingredients (2 points)

- Option 1: Use at least 10 different permanently installed products sourced from at least three different manufacturers that use any of the following programs to demonstrate the chemical inventory of the product to at least 0.1% (1000 ppm)
- Option 2: Use at least 5 permanently installed products sourced from at least 3 different manufacturers that have a compliant material ingredient report or action plan, demonstrating the chemical inventory of the product to at least 0.01% (100ppm).

Construction and Demolition Waste Management (2points)

The most significant number of points which may be attained for this credit is during Phase 1 of the project for Block B, when most of the demolition and construction is going to be carried out. The General Contractor needs to be equipped to divert most of the material being demolished. The second General Contractor, focus will be on Project Finishes and MEP, recycling of construction materials and demolition waste is more difficult in the absence of treatment plants in Malta. Further evaluation would need to be carried out by the LEED AP to identify options to achieve the maximum number of points.

Domestic Waste Seperation on site

Construction Credits

Construction and Demolition Waste Management Plan (2points)

The General Contractor must implement a construction and demolition waste management plan:

- Establish waste diversion goals for the project by identifying at least five materials (both structural and non-structural) targeted for diversion.
- Approximate a percentage of the overall project waste that these materials represent.
- Specify whether materials will be separated or commingled and describe the diversion strategies planned for the project.
- Describe where the material will be taken and how the recycling facility will process the material.

Indoor Environmental Quality Assessment

Construction Indoor Air Quality Management Plan (1 point)

Develop and implement an indoor air quality (IAQ) management plan for the construction and preoccupancy phases of the building.

Post Construction Credits

Indoor Air Quality Strategies (2 points)

This credit obliges the General Contractor to comply with several requirements:

- Entryway systems
- Interior cross-contamination prevention
- OA intake filtration
- Increase ventilation by 30%
- Carbon Dioxide Monitoring
- Additional Source Control and Monitoring

Low emitting Materials (3 points)

Use materials on the building interior (everything within the waterproofing membrane) that meet low-emitting criteria.

Indoor Air Quality Assessment (2 points)

After construction ends and before occupancy, but under ventilation conditions typical for occupancy, conduct baseline IAQ testing for all occupied spaces. Use current versions of ASTM standard methods, EPA compendium methods, or ISO methods, as indicated. Laboratories that conduct the tests for chemical analysis of formaldehyde and volatile organic compounds must be accredited under ISO/IEC 17025 for the test methods they use.

Conduct all measurements before occupancy but during normal occupied hours, with the building ventilation system starting at the normal daily start time and operating at the minimum outdoor airflow rate for the occupied mode throughout the test.

Thermal Comfort (1 point)

Interior Lighting (2points): For at least 90% of individual occupant spaces, it is essential to provide individual lighting controls that enable occupants to adjust the lighting to suit their individual tasks and preferences, with at least three lighting levels or scenes (on, off, midlevel). These credits are confirmed or denied following discussions with the Client and the General Contractor.

Acoustic Performance (1 point)

For all occupied spaces, meet the following requirements, as applicable:

- HVAC Background Noise: Achieve maximum background noise levels from heating, ventilating, and air conditioning (HVAC) systems per 2011 ASHRAE Handbook, HVAC Applications, Chapter 48, Table 1; AHRI Standard 885-2008, Table 15; or a local equivalent.
- Sound Transmission: Important to meet the composite sound transmission class (STCC) ratings, or local building code, whichever is more stringent.

Innovation (6 points)

These credits would need to be discussed further with the client to discuss their implication and efforts to be achieved.

Regional Priority (4 points)

These credits would need to be discussed further with the client to discuss their implication and efforts to be achieved.

Overall Assessment Process

The above assessment clearly indicates that a LEED ID+C Gold Certification is attainable according to the current project specifications. To be able to set a comparison between the optimised improved energy building established in WP 2 and the outcome to the energy modelling in Leadership in Energy and Environmental Design (LEED) methods, it is required to acquire the Bill of Quantities (BOQs) and the results to the Energy Modelling from the client’s end. In the absence of this information, this comparison cannot be carried out. However sufficient groundwork exists to justify a certification process which will enable the client to achieve a LEED ID+C Gold Certification.

LEED ID+C Onsite Training Project

Analysis of Results

The study has shown that data is required to characterize individual buildings in a building stock, and this cannot always be easily extracted from the existing EPC database system. This limits the ability of policy makers to identify typical ‘Reference buildings’ to study the building stock and to establish long term renovation strategies to decarbonize the building stock. To counter such limitations, this framework has established an innovative approach to aid policy makers in clustering and studying the build stock given such limitations. However, moving forward, an automated system that aggregates and extracts all important data from the EPC certificates to a common database should be set-up. Such database would enable clustering to be performed directly on parameters that impact the energy performance of the building stock and allow a validated statistical approach to establish typical ’reference’ buildings for policy makers to study the building stock as detailed in [12].

From the current analysis, some common potential errors in data entry from the EPC certificates could be noted, such as a building having a floor area of 10 m^2. Such errors may be the result of the current software lacking the validation capability to notify assessors when outlier information has been input. Such lack of notifications can make the EPC assessment prone to errors. Thus, such a validation approach should be set-up in future versions of the EPC software. One should look at EU projects such as X-Tendo to understand how to improve software EPC quality checks and improve the quality of the database.

From the study, it has provided in being challenging to obtain energy performance data for individual building stock. Such data should be made more readily available to policy makers at least for commercial buildings. Both Vasallo [113] and Gatt [114] found a large energy performance gap between the outcomes of local EPC software and actual operational energy performance data. Gatt [114] found that such large energy performance gaps can have a profound impact on policy making both in terms of establishing the required energy performance benchmarks and in the measures which should be promoted to decarbonize the building stock. Thus, it is critical that EPC software (default) parameters and 'reference buildings' for the EPBD cost-optimal studies are properly calibrated by making operational data of individual buildings available. The importance of such calibration for EPC software is also highlighted in EPC EU projects, including EPC RECAST [87], X-tendo [88], and U-CERT [89].

The HSBC case-study provided an approach for establishing operational energy performance benchmarks from calibrated building energy models for energy retrofitting to help architects and engineers when undertaking energy renovation. Building energy modelling enables the integrated design team to quantify energy savings more accurately via combinations of energy efficiency measures and identify the optimal combination of measures to satisfy multi-criteria optimization requirements such as maximising comfort, minimizing operational carbon emissions, and minimizing building life cycle costs. Once retrofit projects have been implemented, calibrated building energy modelling can also be used to track the progress of the projects and to verify that the desired energy savings and established benchmarks are being achieved. Despite the importance of building energy modelling to optimise building design in terms of energy performance and comfort, the authors feel that building energy modelling and Building Information Modelling (BIM) are still not being used sufficiently by architects and engineers in the local market, not even for commercial buildings.

The study made reference to the ALDREN project [84] for which the case study touched upon various aspects of the project including the use of calibrated building energy models. ALDREN is a state-of-the-art deep renovation and voluntary energy performance certification process. While it may be considered too detailed for mandatory EPCs, it should serve as a gold standard as to how deep renovation and voluntary certification should be developed, while considering all the sustainable, risk and economic aspects to a project. It also details a Building Renovation Passport (BRP) approach, that outlines a long-term step-by-step renovation roadmap to achieve deep renovation for a specific building.

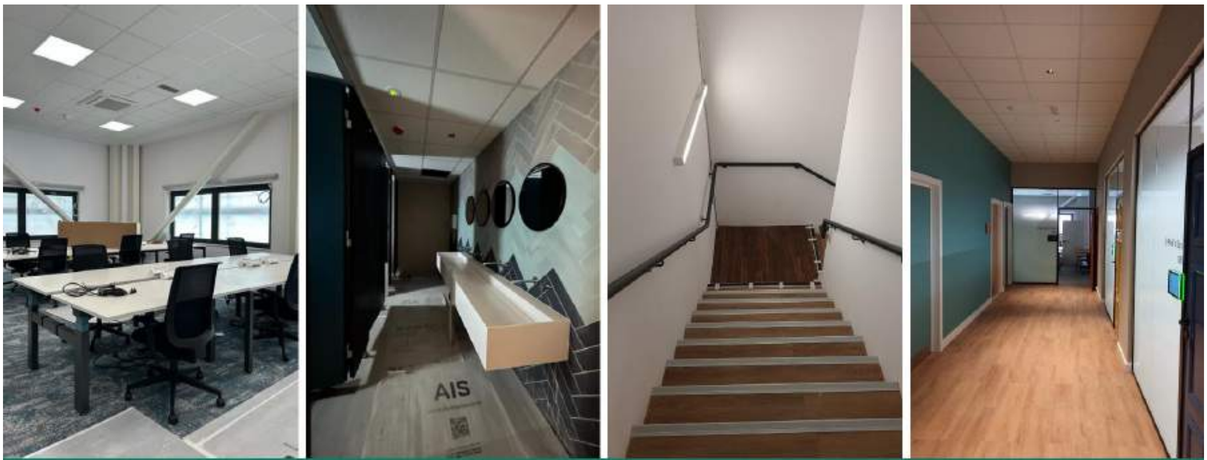
The building data limitations identified in the case study underscore the significance of employing logbooks and building renovation passports to enhance decision-making when calibrating building energy models and undertaking building renovation.

It is being suggested that one considers commissioning this methodological approach to a government office building needing deep refurbishment. This is the optimum way for the full process to be easily understood and documented for other entities to follow especially considering more stringent renovation targets aligned with the European Green Deal [85].

LEED Onsite Training

Given the growing importance and demand for Environmental, Social and Governance (ESG), the framework highlighted the importance of green rating systems such as LEED that move beyond only analysing operational energy performance of buildings. Green Certification methods such as LEED assesses other important sustainability aspects apart from operational energy including water efficiency, IAQ, materials and resources, and innovation amongst others. The document also stressed that building energy modelling and LEED are not two different aspects, but that building energy modelling supports the implementation of LEED. Once again, despite the importance of assessing a building according to multiple sustainability aspects, green building rating systems such as LEED are still not commonly used locally.

Making building energy modelling and green building rating systems in Malta more the run of the mill (for specific targeted projects) even through potential mandatory obligations for buildings of minimum size and environmental impact can be key towards the green building transition while ensuring the fundamental improvement of the EPC software (SBEM-mt [7]and EPRDM [115]) themselves.



Finalising the furnishings

Recommendations

To enhance the popularity of building energy modelling and green building rating systems in Malta, it is imperative to focus on refining the existing EPC software, namely SBEM-mt [7] and EPRDM [115]. Here are several recommendations for improvement:

- **Streamline User Interface:** Simplify the user interface of SBEM-mt and EPRDM to make them more intuitive and user-friendly. Clear navigation and straightforward functions will encourage wider adoption among stakeholders.
- **Enhance Compatibility:** Ensure compatibility with various operating systems and devices to accommodate different users, including architects, engineers, and building owners. This will facilitate broader access and utilization.

- **Improve Performance:** Enhance the speed and efficiency of the software to expedite modelling processes and analysis. Optimizing performance will save time and resources for users, making the software more appealing.
- **Expand Features**: Integrate additional features such as advanced modelling capabilities, energy-saving recommendations, and interactive visualization tools. This will enrich the functionality of the software, catering to diverse user requirements.
- **Provide Comprehensive Training:** Offer comprehensive training programs and resources to familiarize users with the software's functionalities and best practices. Empowering users with adequate knowledge will promote confidence and proficiency in utilizing the software effectively.
- **Foster Collaboration:** Facilitate collaboration and knowledge sharing among users by implementing features for real-time collaboration and data exchange. Promoting a collaborative environment will stimulate engagement and foster innovation within the community.
- **Ensure Regulatory Compliance:** Continuously update the software to comply with evolving energy efficiency regulations and green building standards in Malta. Adhering to regulatory requirements will enhance the credibility and relevance of the software within the industry.
- By implementing these recommendations, SBEM-mt and EPRDM can be strengthened to better serve the needs of users and contribute to the widespread adoption of building energy modelling and green building rating systems in Malta.

Additionally, the following details are a continuation to the above factors:

- The EPC software does not provide a graphical interface to draw the geometry of the model or import the geometry and construction properties of the model via gbXML format [116] from a Building Information Modelling (BIM) or building energy modelling software. Thus, given this limitation, energy performance certification is currently seen as an add-on or after thought in the design process and is only carried out to meet legislative requirements of requiring an EPC rather than a vital tool in the integrated design process. Using such graphical interface tools where one can import and export models from one software to another or perform EPCs and detailed building energy modelling within the same software can facilitate the integrated design process and reduce the time required by designers to perform detailed energy, comfort, and daylighting simulation analysis. Green building certification will also be facilitated given that energy models are more readily available.

- To facilitate the above transition, reduce subjectivity in software inputs and improve harmonization in EPC certification, the EPC software should provide a more comprehensive database of default material and system properties. It should also be updated with the latest technologies such as VRF and battery storage. A more robust validation process to EPC assessor inputs should also be in place.

- The EPC software should be updated from the superseded EN ISO 13790 [117]monthly method to the hourly ISO 52016-1 [118]approach to comply with the latest EPB standards. This will allow the building to assess other sustainability indicators apart from energy performance, including comfort, and indoor air quality as recommended in EPC EU projects such as X-tendo [88]. A water efficiency indicator can also be included as recommended in [119] given that water is a valuable resource in Malta. Such assessments which can also be assessed and validated with actual data from the building operational phase allow EPCs to perform a more comprehensive sustainability assessment and bridge the gap between EPC and green building rating systems.

- The lack of validation in user input in the existing EPC software presents a significant challenge in the utilization of EPC software such as SBEM-mt and EPRDM. This issue stems from the difficulty in ensuring the accuracy and reliability of the data entered by users during the modelling process. One aspect of this challenge is the absence of built-in mechanisms within the software to validate user inputs against predefined standards or benchmarks. Without such validation checks, users may inadvertently input erroneous or inconsistent data, leading to inaccurate simulation results and unreliable energy performance assessments. For instance, users may input incorrect building dimensions, occupancy schedules, or equipment specifications, which can skew the modelling outcomes and compromise the credibility of the analysis. Addressing these challenges requires the implementation of robust validation mechanisms within the EPC software. This entails incorporating error-checking algorithms, data validation rules, and user prompts to guide users in inputting accurate and reliable data. Additionally, providing clear instructions, tooltips, and data validation messages can help users identify and rectify input errors in real-time, minimizing the likelihood of inaccuracies in the modelling results.

- Furthermore, offering comprehensive training and support resources can empower users to understand the importance of accurate data input and equip them with the knowledge and skills to validate inputs effectively. By addressing the lack of validation in user input and enhancing the ease of input validation, EPC software can significantly improve the reliability and credibility of building energy modelling and green building rating assessments, ultimately advancing sustainable building practices in Malta and beyond.

- The existing EPC software lacks graphical user interface (GUI) which plays a crucial role in facilitating user interaction and enhancing the overall usability and effectiveness of the tool. A well-designed GUI of building energy modelling software enhances usability, productivity, and user satisfaction by offering intuitive navigation, visual representation, structured data input, feedback mechanisms, customization options, accessibility features, and comprehensive support resources. By prioritizing the user experience and usability of the GUI, software developers can empower users to effectively leverage building energy modelling tools for optimizing energy performance, promoting sustainability, and advancing the green building industry.

- The existing software lacks a comprehensive database of materials that is essential for supporting accurate energy performance analysis, environmental impact assessment, standardization, and collaboration in the development and optimization of EPC software. By providing users with access to reliable materials data and supporting informed decision-making, the database enhances the effectiveness and sustainability of building design and energy performance evaluation processes.

- The existing software is focused on the operational energy of the building and lacks prioritizing embodied carbon. Having both integrated in the software presents a strategic shift towards a more comprehensive and proactive approach to sustainable building design and construction. By considering the full lifecycle environmental impact of buildings, stakeholders can make informed decisions, reduce carbon emissions, and contribute to a more sustainable and resilient built environment.

- The importance of incorporating climate risk proofing within modelling software. It is essential for enhancing resilience, ensuring regulatory compliance, protecting investments, fostering community engagement, bankability while facilitating climate-resilient infrastructure development. By integrating climate risk assessment tools into modelling workflows, stakeholders can proactively address climate challenges and build a more resilient and sustainable built environment.

Conclusion

In conclusion, Malta's pursuit of its climate targets hinges on the transformative shift towards more energy-efficient buildings and improved construction practices. The groundwork laid by this study establishes a solid foundation, paving the way for further ambitious endeavours in research, policy development, and strategic planning.

Finalising the furnishings

Through this project, HSBC demonstrates leadership in advancing building efficiency research, pioneering initiatives that set a precedent in Malta's construction industry. The study marks a significant milestone, breaking new ground in a context where comprehensive data analysis across stakeholders is limited, particularly in understanding utility usage. Establishing local benchmarks for net-zero carbon buildings is a crucial step forward for Malta, shaping the trajectory of its sustainable development in the sector. To put their commitment into practise, HSBC Malta embarked on the challenge to retrofit their own headquarter building while opting for LEED certification aiming for Gold Certification or better.

While the study focuses solely on commercial office buildings, it underscores the potential for future exploration in residential sectors. It's important to note the challenges encountered, including limited data availability from local authorities and historical data of the case study building. Despite these obstacles, the study's rigorous data collection methods ensure the reliability and accuracy of results, laying the groundwork for informed decision-making and continued progress in Malta's journey towards a more sustainable built environment.

Version	Description	Issued by	Date
01	First Issue	Prof. Ruben Paul Borg	28/09/2023
02	Second Issue	Ing. Abigail Cutajar	13/10/2023
03	Third Issue	Ing. Abigail Cutajar	20/02/2024
04	Fourth Issue	Ing. Abigail Cutajar	03/03/2024
05	Fifth Issue	Ing. Abigail Cutajar	10/03/2024

WP3 (PART 1): Regulations and Policies

Introduction

This document serves as a comprehensive review of building sustainability and energy performance regulations in the Maltese Islands, specifically focusing on energy efficiency within the framework of Maltese building guidelines and regulations. The aim of this report is to provide an in-depth analysis of the existing landscape, identifying potential gaps in legislation and policies pertaining to energy efficiency in buildings.

In pursuit of this objective, the report offers background information to contextualize the current regulatory environment. By critically examining the prevailing framework, the report seeks to pinpoint areas where improvements or adjustments are necessary to enhance energy efficiency standards in buildings across Malta.

Furthermore, the report adopts a holistic approach, acknowledging the intrinsic link between building sustainability, energy performance, and environmental conservation. Through this lens, it endeavours to highlight not only the regulatory gaps but also opportunities for promoting sustainable building practices and achieving long-term environmental objectives.

Ultimately, this report seeks to provide valuable insights and recommendations grounded in the existing legislative framework, aiming to facilitate informed decision-making processes and foster advancements towards a more sustainable built environment in Malta.

Building Regulations in Malta

The New Building Codes Framework and National Regulations

The Building Industry Consultative Council (BICC) embarked on the task of preparing the local Building Codes. This development was aligned with the publication of legal notices establishing a legal framework for the construction sector. These approaches, though primarily focused on building construction, have a direct bearing on building sustainability, with due consideration of conservation of resources and recycling of waste, design for deconstruction principles and a wider appreciation of building sustainability in the different codes (it is noted that a dedicated code was proposed for Building Sustainability - Section 7 - nevertheless sustainability is seen as a horizontal theme across all standards).

Seven Codex were proposed, and technical expert committees were set up prepare the documents for consultation:

- Section 1: Demolition, Excavation and Building
- Section 2: Fire - Fire Safety and Toxic Materials
- Section 3: Environment - Hygiene and Health
- Section 4: Safety - Access and Egress
- Section 5: Noise
- Section 6: Energy
- Section 7: Sustainability

Additional supporting legislation/regulations addressing demolition, excavation and construction emerging during the past 5 years are summarized below:

- 136/19: Avoidance of Damage to Third Party Property – June 2019
- 180/19: Appointment of the Site Technical Officer – July 2019
- 420/21 Times for Demolition and Excavation – October 2021
- 468/21: Neighbourhood Scheme (Architects – Developers) – November 2021

Key areas of activity evolving in relation to Demolition, Excavation and Construction, and in this context refer also to:

- Skill Cards (BICC)
- Safety Cards (BICC)
- Stakeholder' Obligations – November 2019
- Construction Management Site Regulations – December 2022
- Licensing of Contractors
- Minimum skill requirements for workmen on site
- Party wall Legislation
- Eurocodes National Annexes Expert Structural Eurocodes Committee - MCCAA

The activities for the development of the National Building Codes and Regulations during the past years included various technical experts and included consultation with the key stakeholders in the industry. It is understood that this important and ongoing activity, presently led by the Building and Construction Authority, is a fundamental and essential step supporting a structured framework towards higher quality in the construction sector.

Kamra Tal-Periti regulatory framework proposal

Like various entities such as BICC, the Kamra Tal-Periti (KTP/Kamra) has been proposing new building codes to promote standards and improved quality in the construction industry.

The Kamra tal-Periti (KTP) has put forth a regulatory framework [120] that aligns with international standards, addressing gaps in building regulations. The purpose of KTP's recommendation is to bridge regulatory disparities in Malta's construction sector.

The document delves into key chapters, with Chapters 2 and 3 providing an overview of current building and construction regulations in Malta. It distinguishes between building regulation, focusing on the product's performance, and construction regulation, governing the building process. These chapters underscore Malta's fragmented regulatory landscape and the resulting bureaucratic hurdles, advocating for rationalization and consolidation to enhance efficiency.

Chapter 4 offers a comprehensive review of Europe's best regulatory practices, serving as a benchmark for KTP's proposals. This comparative analysis ensures the viability and industry acceptance of the recommendations.

Chapter 5 presents the core of KTP's proposals, emphasizing the principle that each construction phase should be overseen by appropriately trained and licensed professionals. This necessitates a clear delineation of responsibilities among stakeholders, ensuring accountability throughout the construction process.

The KTP proposal [120]is based on ten important principles:

1. The separation of planning permit and building permit processes;
2. Clear well-organised regulatory processes designed to promote public safety, and quality, in the interest of the consumer, rather than being focused on ascribing blame post-accident;
3. Clear distinction between the regulations governing building (the permanent works) and those governing construction processes and temporary works;
4. The BCA is to take on the consolidated role of the assessment of buildings, building authorisations, enforcement, and monitoring of the construction processes, with the 22 public entities hitherto entrusted with the different areas of interest, becoming key stakeholders in the drafting of regulations and guidance documents.
5. Major projects and public buildings to be subjected to an independent review, particularly in terms of structural design and fire engineering through the introduction of a new professional figure (Engineering Auditor).
6. Contractors to be solely responsible for the process of construction, including temporary works, and would therefore have full possession of construction sites for the duration of the works. They would obviously need to have specific skills and should therefore be classified and licensed according to such skills.
7. The enforcement of construction regulations to be delegated to private service providers, licensed by the BCA, referred to as Building and Construction Inspectors (BCIs).
8. Contractors to be required to certify that the executed works comply with the design instructions, and with the requirements of the Construction Products Directive.

9. The construction phase will be concluded by the issuance by the BCA of a Compliance Certificate, which, *inter alia*, authorises that the building can be brought into use.
10. Post-occupancy checks and audits to be undertaken as pre-determined by the BCA to ensure the continued compliance of the structure with building regulations.

The KTP has been quoted as proposing the following: “rather than the series of entities that have been set up to regulate the sector, giving rise to a series of gaps in the system, the KTP is proposing one central authority that would set building and construction regulations as well as issue licenses of all labourers working in construction” [121].

In the context of the KTP proposal, the organisation is proposing a system of certifications and approved documents, underpinned by two sets of codes, the Building Codes, and the Construction Codes.

“Building codes would regulate the performance of the finished works, in accordance with the essential requirements for the building to be deemed safe, functional, and fit for occupation before being brought into use and remaining so after being brought into use. It is envisaged that these building codes will be primarily performance-based or functional, with prescription avoided as much as possible, to avoid rapid obsolescence and encourage innovation. Guidance documents, providing non-mandatory templates satisfying regulations will provide best practice and widely accepted norms, which would allow fast-track BCA approval. If this was to be adopted, the following components are likely to be addressed:

1. Structure
2. Fire Safety and Prevention
3. Site Decontamination
4. Waterproofing
5. Toxic Materials and Substances
6. Sound Insulation
7. Ventilation
8. Sanitation, Plumbing and Hot Water
9. Water Conservation

10. Drainage
11. Waste Management and Disposal
12. Combustion Appliances and Fuel Storage
13. Protection from Falling, Collisions and Impact
14. Energy Conservation
15. Access
16. Lifts, Escalators and Travellators
17. Electricity
18. Security
19. Information and Communications Technology
20. Illumination
21. Materials, Products & Workmanship

Construction codes would regulate the construction processes, including all temporary works, required to ensure safety and minimum inconvenience. The following components would be covered:

1. Health & Safety in and around Construction Sites
2. Construction site operations
3. Demolition Works
4. Ground Investigation Works
5. Earthworks
6. Construction and Alteration Works
7. Temporary Works
8. Noise Abatement
9. Environmental Protection
10. Waste reduction and disposal
11. Machinery, Plant and Equipment
12. Insurance

KTP is also recommending the consolidation of the pre-, peri- and post-construction administrative processes, including the submission to the BCA of documentation relating, for example, to the appointment of licensed contractors and professionals, the avoidance of third-party damage, EPC design rating, commencement notices, health and safety files, and compliance certification. The construction process is therefore divided into four main phases:

1. Pre-construction phase (design and pre-commencement)
2. Construction phase (execution)
3. Completion phase (compliance certification, handover, and occupation)
4. Post-occupancy phase (post-occupancy review and certification)

For the pre-construction phase, KTP is proposing streamlined processes, depending on the project typology (for example, regular procedure for major projects, light procedure for medium/small projects, procedure by building notice for minor works, exempt) including:

1. The appointment of Principal Submitting Person, PSP, by the developer;
2. The submission of building permit application to the BCA, together with construction drawings and specifications in accordance with the Building Codes, including the identification of the various professionals involved in the project at design stage;
3. The grant of the building permit;
4. The appointment of Building and Construction Inspector (BCI);
5. The submission of the commencement notice, including particulars of BCI and the various professionals and contractors involved in the project at implementation stage; and all other requirements as set out in the construction codes.

The KTP is proposing that during the construction phase, works can only be undertaken by trained and duly licensed contractors, employing operators who also have been appropriately trained in their specific trades. The contractor shall take possession of the site, shall be responsible to control access to such site, to prevent unauthorised access, and to ensure the safety of all visitors, in particular the PSP or delegates of the PSP, and the BCIs. For the completion phase, the Kamra is proposing the inclusion of the following steps:

1. The submission of the completion certification by the PSP, including as-built drawings and the various certifications drawn up by the professionals and contractors involved in the project;

2. The issuing by the BCA of a compliance certificate based on certification submitted by the professionals and contractors involved in the project, which would include the following information:
   a. confirmation that the building is safe for occupation;
   b. authorisation to the contractor/s to hand over the site to the developer for occupation;
   c. the requirement for post-occupancy review and certification of the building, indicating type and frequency.

For post-occupancy reviews, the Kamra tal-Periti (KTP) recommends regular inspections, conducted at appropriate intervals, focusing on critical components essential for public safety, ongoing functionality, and compliance with building regulations.

In the final segment of its proposal, KTP provides an implementation plan and a tentative timeline for a seamless transition to the proposed system. The Kamra is confident that, with collective effort from all stakeholders, this timeline can be effectively met.

KTP's proposals are in harmony with the development of codes by the Building Industry Consultative Council (BICC) and Building Control Agency (BCA), as well as the strategic framework at the national level. Additionally, the proposals address key issues that further enhance sectoral development and directly contribute to building sustainability.

Standards and Guidelines

National standards play a crucial role in meeting the unique needs of a nation and reflect the special circumstances I the territory. These standards become necessary when international or European standards do not adequately cover certain aspects, remaining voluntary until legislation adopts and enforces them.

Specific areas requiring such action include the implementation of green roofs, considering the distinct characteristics of Maltese buildings, and the construction, demolition, and recycling sectors due to the nature of building materials and techniques in the Maltese Islands. In the latter, therefore, the construction industry relies on particular materials and structural elements, resulting in varied requirements for deconstruction and generating specific waste streams that can be classified, processed, and redirected for reuse or recycling.

The concept of design principles for deconstruction is also introduced, tailored to the Maltese context, given the unique nature of buildings in certain categories. The document outlines a series of National Standards developed for Malta, addressing specific challenges related to building construction and the sustainability of structures in the Maltese islands, as detailed in the accompanying table.

Table 40: Standards to improve the building industry

Standard	Title
SM 5100:2015	Photovoltaic Installations - Requirements for electrical safety of single-phase systems
SM 3800:2015	Accessibility for all in the Built Environment
SM 5200:2017	Solar Photovoltaic (PV) Installations - General requirements for PV systems installations
SM 3700:2017	Green Roofs - Criteria for the planning, construction, control and maintenance of Green Roofs
SM 810:2022	Recycling oriented deconstruction, controlled excavation works and classification of waste

The Construction and Demolition Waste Standards – Generic

The recently established Maltese National Standards, SM810 (Recycling-Oriented Deconstruction and Classification of Construction Demolition and Excavation Waste) and SM820 (Classification of Recycled Aggregate), crafted by the Malta Competition and Consumer Affairs Authority (MCCAA) [122], offer a structured framework for categorizing recycled aggregate and its utilization as a valuable resource. These standards pave the way for the future harnessing of this resource within Malta, laying a solid foundation for its sustainable exploitation.

C&D waste is a priority waste stream due to the substantial amounts of such waste generated. There is a high potential for reuse and recycling of waste and by-products. The Construction and Demolition Waste Strategy [123]for Malta supports the transition towards a more circular economy and closes the loop of construction products life cycle. The quality of recycling and recovery of this waste stream needs to be improved for market conditions to be developed to increase the demand for secondary raw materials. The National Strategic Framework led to the design, development and eventual implementation of National Standards for Excavation, Construction and Demolition Waste in Malta. The MCCAA has introduced two pivotal National Standards, SM810 and SM820, aimed at classifying recycled aggregate derived from construction and demolition (C&D) waste, thereby encouraging its reuse. With the substantial volume of C&D waste generated, there exists considerable potential for recycling and reutilization. Malta's C&D Waste Strategy underscores the importance of a circular economy, advocating for enhanced recycling quality and the development of markets for secondary raw materials.

These National Standards are instrumental in promoting resource exploitation and the utilization of industrial by-products and recycled materials for various building products, including insulation and low-impact materials, aligning with sustainability principles.

Developed under the auspices of the University of Malta and the MCCAA Technical Committee TC800, the standards framework comprises two key documents: (1) Recycling-Oriented Deconstruction and Classification of Waste, and (2) The Classification of Recycled Aggregate. The National Technical Committee (TC800) spearheaded the final presentation and development of these standards, leading to public consultation and eventual publication of the C&D Waste Standards.

In 2022, SM810 was officially published, addressing the requirements outlined in National Strategy Measure No. 1 for the Construction Industry. Following public consultation, it was established as a new national standard: SM 810:2022 - Recycling-Oriented Deconstruction, Controlled Excavation Works, and Classification of Waste - Requirements for Planning and Execution. Its incorporation into the Construction Management Site Regulations (S.L. 623.08) [124], as per Legal Notice 340 of 2022 by the Government of Malta, rendered it mandatory across the Maltese islands.

Meanwhile, SM820 - Classification of Recycled Aggregate, is currently undergoing final development and review by the MCCAA committee TC800, further bolstering Malta's commitment to sustainable construction practices.

SM810: Recycling Oriented Deconstruction, Controlled Excavation and Classification of Waste

The SM810 Standard is intended as a guide for good practice and a reference for building owners, developers, designers, and contractors. The document is set to prioritise the reduction of waste generation and highlights the importance of saving raw material resources. The Standard is intended to serve as an aid for the construction industry stakeholders to facilitate planning, classification of waste and conducting demolition operations, through deconstruction, and excavation operations with a view to reuse and recycling: the standard refers to recycling oriented deconstruction and controlled excavation works to reduce/eliminate waste disposal. This Standard also refers to the code of practice for demolition operations as presented in BS 6187:2011 and to SM 820 Classification of Recycled Aggregates. The Standard applies to all demolition, deconstruction, and excavation work in all projects in the Maltese Islands. It is noted that the applicability of this Standard should take into consideration the type and the scale of deconstruction and excavation being undertaken and work practices on different sites should be adapted accordingly.

The framework as presented in SM810 applies also to waste generated during construction operations. The deconstruction process at end of life of a building needs to be supported through the principle of design for deconstruction. The goal of the Design for Deconstruction is to responsibly manage end-of-life building materials to minimise consumption of raw materials. SM810 refers to Deconstruction and Controlled Excavation, with the objective of reducing waste generated, and reusing/recycling building elements and components [18]. The Standard also promotes the reduction of waste primarily through the adaptation and retrofit of existing building assets. Deconstruction is encouraged, instead of demolition for the following reasons:

- Deconstruction allows for reduced generation of waste;
- Preservation of primary raw material resources;
- Reducing reliance on backfilling;
- Better management of waste at end of life, and facilitation of reusing and recycling.

The Standard underscores the significance of Controlled Excavation as a fundamental principle in construction operations. Waste classification is highlighted as a crucial step in effectively managing waste generated during deconstruction and controlled excavation processes. Any waste produced during these activities must adhere to the waste hierarchy outlined in Regulation 4A of S.L. 549.63 Waste Regulations [125].

Furthermore, the Standard mandates the creation of a comprehensive waste catalogue. It provides developers and contractors with essential guidance on best practices for planning and executing deconstruction and controlled excavation operations. Deconstruction activities must be meticulously planned with a structured approach and supported by engineering assessments. The emphasis is placed on recycling to maximize the recyclability of materials derived from building and excavation sites.

Controlled excavation is recommended as the primary method for excavation sites, with careful consideration given to potential resource extraction in block form to minimize waste generation. Notably, excavation waste, particularly limestone, constitutes the largest volume of waste generated in Malta.

Storage requirements are outlined in the Standard, recognizing that deconstruction and controlled excavation processes may necessitate temporary storage of waste streams before recycling. Additionally, SM810 emphasizes the importance of Skills and Training, requiring operators in deconstruction, demolition, and excavation works to adhere to National Occupational Standards, including those for Excavation and Demolition. Training regimes and skill cards are essential components of this framework to ensure competency and compliance among operators.

SM820: Classification of Recycled Aggregate (Draft for Consultation, Stakeholder Dissemination)

The Standard SM820 for the Classification of Recycled Aggregate sets out technical engineering attributes for the classification of waste aggregate, enabling its exploitation as a resource. SM820 provides a first classification of Construction, Demolition and Excavation waste in the Maltese Islands. The purpose of the standard is to enable the classification of waste to transform it into a resource for construction which is of adequate quality and safe to consumers and the environment. The standard gives the opportunity to different stakeholders, to exploit waste, as a key resource in construction, enabling the production of construction materials for intended applications. The classification is designed to respect the possible current and future applications of materials in construction, in the context of the construction products regulations, and to provide the designer and producer with the necessary tools to enable wide exploitation of materials with respect to the principles of sustainable use.

Energy Performance Certificates in Malta

Background and Purpose

This section presents a review of the Energy Performance Certification, in particular the tasks and functions of an EPC, linking it to current political goals and strategies of European Commission. Key solutions and leadership in the specific area of activity towards the next generation of EPC are presented. A link is made to the UN Sustainable Development Goals (SDGs) [126], while considering Malta's climatic conditions, as well as its political system and its real estate market. Furthermore, the Maltese context is considered in relation to its energy system, providing useful information for specific actors and groups such as policy, clients, owners, stock owners, tenants and users, and public authorities.

The role of EPCs in Europe

The following resources serve as references for both general and European approaches:

- Energy [127]
- Energy Efficient Buildings [128]
- Energy Performance of Buildings [129] and Energy Efficiency Directive [130]
- Building Performance Institute Europe (BPIE) – EPCs across the EU [131]

- The following international sources could serve as references to a national approach:
- United Kingdom: Government of United Kingdom – Buying or Selling Your Home – EPCs [132]
- Luxembourg: Ministry of Economy, Directorate for sustainable energies - Implementation of EPBD in Luxembourg [133]

- Germany: Federal Ministry for Economic Affairs and Energy – Energy Efficiency Strategy for Buildings – achieving a virtually climate neutral building stock[134]
- Recommendations for further developments: BPIE - EPCs: Assessing their Status and Potential [131]

As from 1st January 2023, office buildings are being requested to have at least an energy label C (an energy index of 1.3 or better). If an office building does not comply with this requirement, it can no longer be used as an office from this established date.

European Union requirements applicable to EPCs [58]

Member States of the European Union are required to enact measures to establish a certification system for assessing the energy performance of buildings. This Energy Performance Certificate (EPC) should encompass various aspects including the building's energy efficiency and reference values like minimum energy performance standards. This facilitates comparisons and evaluations of energy performance for building owners or tenants. In addition, the EPC may incorporate supplementary details, such as annual energy consumption for non-residential buildings and the proportion of energy derived from renewable sources in the overall energy consumption. The EPC must provide recommendations for cost-optimal or cost-effective enhancements to the energy efficiency of a building or building unit unless such improvements are deemed unreasonable compared to existing energy performance requirements.

These recommendations within the EPC should encompass:

(a)	measures carried out in connection with a major renovation of the building envelope or technical building system(s); and
(b)	measures for individual building elements independent of a major renovation of the building envelope or technical building system(s).

The suggestions in the Energy Performance Certificate (EPC) must be possible to effect for the specific building. It can also estimate how long it will take for the return of investment or how much money they will save over time.

The EPC should tell the owner or tenant where to find more detailed information about the suggestions it makes. This includes whether the changes are worth the cost. For this purpose, they look at things like how much energy will be saved and how much energy costs. It should also explain what steps need to be taken to make the suggested changes. Other useful information, like energy audits or financial incentives, might also be included.

Depending on the rules in each country, governments should encourage public authorities to lead by example when it comes to improving energy performance in buildings. This means they should follow the suggestions in the EPC for buildings they own while the certificate is still valid.

Certification for individual parts of buildings can be done in different ways.

Recommendations within the EPC should encompass:

(c)	on a common certification of the whole building; or
(d)	on the assessment of another representative building unit with the same energy-relevant characteristics in the same building.

Certification for single-family houses can be established by evaluating another representative building of comparable design, size, and actual energy performance quality, provided that such equivalency is assured by the expert issuing the Energy Performance Certificate (EPC). The validity period of the EPC must not exceed 10 years.

By 2011, the Commission has mandated to develop, in consultation with relevant sectors, a voluntary common European Union certification scheme for assessing the energy performance of non-residential buildings.

Current situation in Europe in relation to the use of EPCs [135]

The European Union has established clear legislative frameworks to reduce energy demand from buildings. The directives on the Energy Performance of Buildings (EPBD) (2018/844/EU) [136]and on Energy Efficiency (EED) (2018/2002/EU) [130]are being implemented by the EU Member States to this end. Under the EPBD, EU member States have established energy performance certification systems with independent mechanisms for implementing and controlling national pathways towards improving the energy efficiency of buildings.

In this context, EPCs are instruments that contribute to the improvement of the overall buildings' performance in a transparent and comparable way across Europe. EPCs were first introduced under the EPBD in 2002 [137], and in 2010 the recast EPBD [129]added a set of new requirements to improve the quality, usability, and public acceptance of EPCs. Not to be confused with Energy Performance Contracting (which is also commonly abbreviated as EPC), the purpose of an EPC is to provide information on a building's energy performance rating and to make recommendations about cost-effective improvements.

Energy certification can also be a means of informing consumers and can influence the building's property value. The report by the European Commission's Joint Research Centre supports 'de-risking' activities by evaluating existing literature about the impact of energy efficiency improvements on the value of property through the impact on operational costs. The contribution of EPCs to so-called green premiums and brown discounts are also analysed.

EPCs may also include information on non-energy parameters, such as comfort. A 2018 report by BPIE puts a spotlight on Indoor Environmental Quality (IEQ) parameters. It presents national cases and initiatives and provides recommendations on how to integrate IEQ in national and EU policies.

The European Commission supports concerted actions that assist member states to implement EU sustainable energy legislation effectively. The EPBD Concerted Action [138] facilitates the sharing of experiences between national authorities responsible for implementing the EPBD. One of its core teams focuses on EPCs, including issues of compliance, use of databases, and training of inspectors. These topics are developed around the idea of feeding into three major pillars linked to EPCs:

1. Quality (inputs, outputs, data, methodologies, experts),
2. Visibility (awareness, communication, image, perception of EPCs, range, how EPCs call to action, advertising),
3. Usability (information, how triggers lead to action, choices made, interoperability).

The EPBD concerted action published a report on the status of certification, control systems and quality across the EU's Member States plus Norway, in 2018. The report discusses the procedural steps to carry out certification and inspections in buildings, as well as measures the countries are taking to ensure the public's acceptance and awareness of EPCs. Some countries have designed their EPCs to consider the possibility of carrying out step-by-step renovations to improve energy performance in stages over time. The Concerted Action also publishes factsheets, including one on member states' experiences in changing EPC scales and layouts, and another on the EPCs impact on property value." [138]

Recommendations for further development

The following include some key possible recommendations towards the further development of EPCs.

- Improvement of transparency in real estate markets;
- Provide information on hidden characteristics of buildings;
- Overcome adverse selection;
- Stimulate investors to pay for better energy performance;
- Stimulate owners to pay for deep energy retrofit;
- Support developers to send out signals of good building performance to markets;
- Allow tenants and buyers to search for buildings with good energy performance;
- Support tenants and buyers in final decision making;
- Support banks/ financial institutions in risk assessment;
- Support appraisal specialist with by providing data;
- Support stock owners (real estate companies) in portfolio analyses;
- Support national government in showing leadership and good examples;
- Support national statistics to learn more about national building stock;
- Support energy supplier to learn more about current and future energy demand;
- Provide basis for calculation and forecast of green-house gas emissions.

Reference is made to *key and relevant issues* from a 2010 BPIE report relating to energy performance certificates across Europe and a mapping of national approaches [139].

EPCs were introduced for the first time in the Energy Performance of Buildings Directive (EPBD) in 2002, and in 2010 the EPBD recast added a set of new requirements to improve the quality, usability, and public acceptance of EPCs. To date, all 28 member states formally implemented the EPBD requirements in their national legislations.

In some member states where the EPC schemes have a long tradition, a positive impact on the real estate market has been recorded. Access to EPC data repositories has shown a positive impact on the market value of energy efficiency improvements, contributing to the market transformation the EPBD aims at.

The main aim of the EPC is to serve as an information tool for building owners, occupiers, and real estate actors. Therefore, if used well, EPCs can be a powerful market tool to create demand for energy efficiency in buildings by targeting such improvements as a decision-making criterion in real-estate transactions, and by providing recommendations for the cost-effective or cost-optimal upgrading of the energy performance.

EPCs have the potential to become effective instruments to track buildings' energy performance and the impact of building policies over time as well as to support the implementation of minimum energy requirements within the regulatory process.

With the EPBD recast (2010)[129], member states were asked to revise their national legislation regarding the EPC schemes in place and to further improve them on a broad range of aspects, including:

- Introduction of an independent EPC control system (art. 18);
- Assuring the competence of the certifiers in the accreditation procedure (art. 17);
- Introduction of penalties for non-compliance, including for poor quality of the EPCs (art. 27);
- Increasing the availability of EPCs in sale and rent transactions and the visibility of the energy label in commercial advertisement (art. 13).

While this is not specifically requested by the EPBD, 24 member states and Norway have to date established centralised EPC registers.

The implementation of the EPC schemes at member state level is still ongoing and is challenged by public acceptance and market-uptake.

Reference is made to Key Recommendations (BPIE, 2010)[131]

- There is a need to consistently improve the enforcement of the EPC schemes in member states and strengthen the monitoring of their compliance both at member state and European levels.
- There is a need to strengthen the role of EPCs in the context of national legislation, especially for renovation policies and programmes.
- There is a need to introduce further quality assurance measures, especially during the early stages of the certification process.
- Digital tools for quality checks of the EPC data should be used, such as plausibility check in the calculation software and/or the EPC registers.
- There is need for guidance in the development of centralised EPC registries, not only to support the independent control system, but as a tool to map and monitor the national building stock.
- There is a need to promote the effective use of the EPC data.
- There is a need for independent evaluation of the effectiveness of the EPC scheme.

Current activities on a European level

Current activities in the European context need to be considered in view of the specific activities and their consequences with regards the Energy Performance Certification System.

Table 41: Activities and the roles of an EPC

Activity	Consequences for a role of EPCs
Green Deal	EPC can help to demonstrate good energy and carbon performance to the market
Circular economy	If a bill of materials will become part of the EPC as an appendix, this can support a circular economy (recycling of products and systems)
Renovation wave	Recommendation for deep energy retrofit and the demonstration of economic effects inside an EPC can support the idea of renovation wave – including a refurbishment roadmap
Green Finance / taxonomy	In the near future banks will be requesting energy and carbon performance reports – EPCs are becoming a safe source of such information.

Climate neutral continent	EPC must contain carbon performance related information (perhaps including embodied emissions) – this can support climate mitigation actions
Building stock observatory	A national database with EPC-based information will support national statistics and action for further development of building stock
Nearly zero carbon buildings	EPC can communicate the achievement of nZEB-level
Digital logbook	EPC can become a part of a digital logbook. A digital EPC can "calculate" the emissions and will signal need for maintenance
New European Bauhaus	Requirements for energy and carbon performance will become part of next generation of design principles

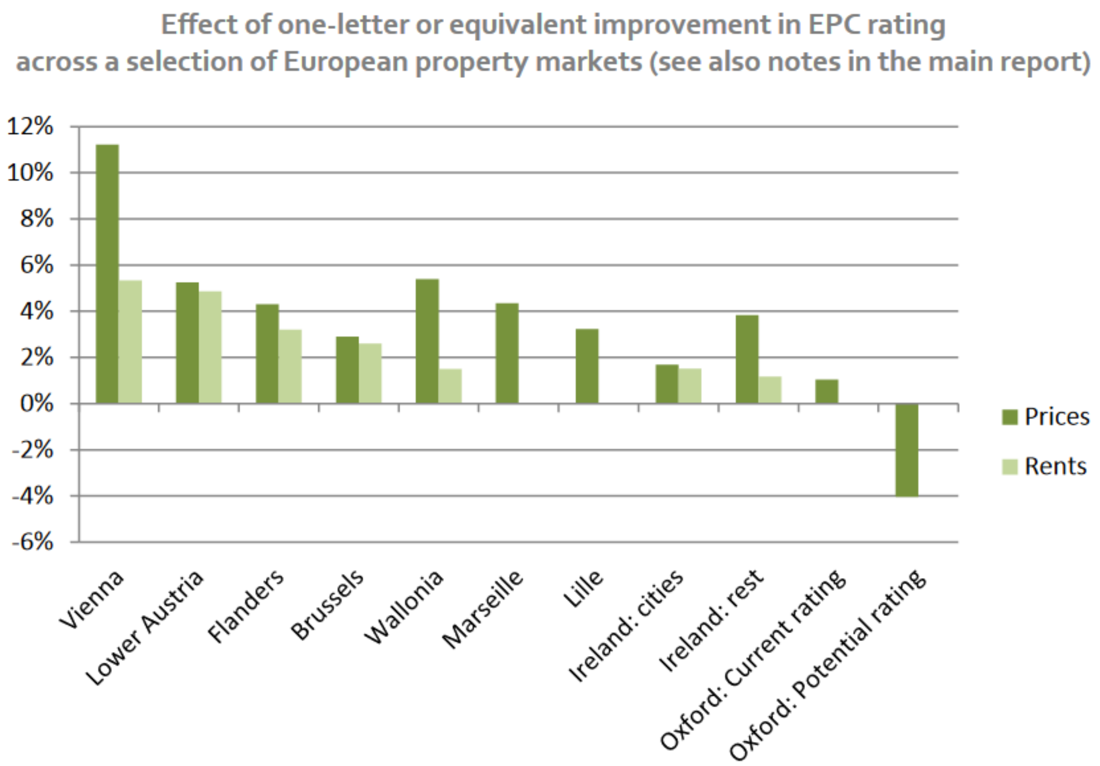


Figure 46: Effect of improving in pricing based on a single increase in EPC rating level [140]

Malta’s Current Scenario

Overview

The scope of an EPC certificate is to guide new homeowners as to the building’s energy rating. In fact, an EPC describes the energy performance of a particular building just like a household energy label appliance shows the corresponding Energy Rating (A++, A+, etc). An EPC certificate is obtained after an energy performance audit has been performed according to an established methodology by L.N. 261/2008 [141] and duly registered with the Malta Resources Authority.

An EPC is based on the following dwelling general criteria:

- The dimensions: based on the internal surface areas and heights; i.e., the internal volume;
- The type and building geometry: based on the perimeter walls and roofs, building materials, orientation, shading and U values;
- The building’s glazing: based on the door and window materials, orientation, shading and U values;
- External and internal heat gains / losses;
- Draughts and internal ventilation;
- The types of systems used for domestic services: based on the water heating, lighting, heating, and cooling;
- The renewable systems.

Directive 2002/91/EC of the European Parliament and of the Council of the European Union [137]requires member states to adopt this energy performance of buildings directive. The objective of this directive is to promote the improvement of the energy performance of buildings within the community, considering outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness.

In Malta, the 2002/91/EC directive was transposed via Legal Notice 261 of 2008 [141]. It is imperative to note that as from 2nd January 2007, all new buildings and existing buildings that undergo major renovation or alterations are to conform to the minimum requirements on the energy performance of buildings referred to as Technical Guidance Document F [142].

Following this directive implementation, a local system and course was set up accordingly by the Ministry of Resources and Rural Affairs (MRRA) and the Malta Resources Authority (MRA) to train Energy Performance Assessors to issue the necessary EPCs. Nowadays this is managed by the Buildings and Construction Authority (BCA).

Legislative Background

The Energy Performance Standards for residential and other buildings have been the basis for policies on energy conservation in buildings since 2006 in Malta. Building regulations impose minimum requirements on the energy performance of buildings, promulgated through the Technical Guidance: Minimum Energy Performance Requirements – Doc F, 2006 [143]

- **Document F - Conservation of Fuel, Energy and Natural Resources, 2006 (effective for new buildings validated by the 31.12.2015) was p**ublished on 6th October 2006. Technical Guidance Document F was intended to apply to new buildings and existing buildings that undergo major renovation or alteration, whose building permit application is received by the Malta Environment and Planning Authority on or after the 2nd January 2007 [143].
- **L.N. 261 of 2008: The Energy Performance of Buildings Regulations,** published on 21st October 2008, states that as from 2nd January 2009, an owner or his agent must obtain an EPC when a building is being constructed, sold, rented, or undergoing a major renovation of more than 20% [141].
- **L.N. 376 of 2012: The Energy Performance of Buildings Regulations, 2012** [144]**.** The Energy Performance of Building Directive (2010/31/EU) [129]has been transposed into Maltese law by means of Legal Notice 376/12 [145]. According to this legal framework, the Building Regulation Board has been tasked with updating current Minimum Energy Performance Requirements as informed by cost-optimality studies. The methodology for calculating the energy performance of buildings shall be in accordance with the common general framework set out in Schedule I of LN 376/12. Schedule I states that the methodology for calculating the energy performance

of buildings should consider European standards and shall be consistent with relevant EU legislation, including Directive 2009/28/EC on the Promotion on the Use of Energy from Renewable Sources[146].

- **L.N. 434 of 2015 BUILDING REGULATION ACT (CAP. 513): Conservation of Fuel, Energy and Natural Resources (Minimum Requirements on the Energy Performance of Buildings) Regulations, 2015** [147]. The Conservation of Fuel, Energy and Natural Resources (Minimum Requirements on the Energy Performance of Buildings), published by the Building Regulation Office in August 2015, as Documents F - Part 1: Minimum Energy Performance Requirements for Buildings in Malta and Part 2: Minimum Energy Performance Requirements for Building Services in Malta, was considered as applicable for new and renovated buildings, from 1st January 2016. It set minimum requirements for the conservation of fuel, energy and natural resources.

- **The Nearly Zero-Energy Buildings (NZEB) Plan for Malta**[148]. This plan was published in 2015 with the objective of mapping a way on how to increase the number of nearly-zero energy buildings in Malta.

- **Technical Document F**: Effective from 1st January 2016, and applicable to Malta, Part 1 sets minimum energy performance requirements for buildings and Part 2 sets minimum energy performance requirements for building services. This document has now been updated into three separate documents Technical Document F Part 1, Part 2 and Part 3. These documents will become effective as from 1st of July 2024 [149]

- **L.N. 47 of 2018 Building Regulation Act (CAP. 513) on Energy Performance of Buildings Regulations:** This regulation was published on 13th February 2018, and intended to transpose Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings [4] and to give effect to its provisions. These regulations promote the improvement of the energy performance of buildings within the territory of Malta, considering outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. L.N. 47/2018 states that the methodology for calculating the energy performance of buildings shall be in accordance with the common general framework set out in Schedule I as established and implemented through the Energy Performance Rating of Dwellings in Malta (EPRDM) [150]and Simplified Building Energy Model (iSBEMmt), supplemented by the User's

Guide to iSBEMmt [151]and the Technical Guide to iSBEM, as issued and updated from time to time and as communicated in the Gazette. Schedule I states that the methodology for calculating the energy performance of buildings should consider European standards and shall be consistent with relevant EU legislation, including Directive 2009/28/ EC on the Promotion on the Use of Energy from Renewable Sources[146].

In Malta, the **EPRD** methodology is used for dwellings while the **iSBEM**mt methodology is used for Non-Dwellings.

Ongoing Strategies and Initiatives in Malta

Long Term Renovation Strategy to 2050 [152]

Table 42: Long Term Strategy and the effects of having an EPC in place

Long Term Strategy in Malta	**Ramifications for Energy Performance Certificates (EPCs)**
▪ Information – campaign, benefit of more energy efficient buildings ▪ Regulation - minimum standards will be applied to all new buildings ▪ Enforcement – more focus, benchmarking ▪ Financial Incentives – reach standards beyond minimum cost optimal levels; residential and non-residential sectors; grants, fiscal and bank rate incentives	*The introduction of a further developed EPD can be part of an information campaign.* *EPC is linked to fulfilment of legal requirements* *EPC can support benchmarking through performance classes, can be the basis for incentives*
▪ Fiscal incentives for developers to abide by updated regulations.	*Banks can execute data from an EPC*

▪ Subsidies, grants for renovation - standards with maximum benefits reducing energy use. ▪ Bank rates incentives (financial instruments) - investment in building renovation. ▪ Grants - domestic sector; Caps incentive amount /applicant - maximise grant no. ▪ Incentives - Commercial sector and funding grants for public buildings (inc. EU funds) ▪ Long-term action – Promote smart technology (electro mobility plan MNEAP)	
▪ Minimum standards applied to all new buildings, updated minimum standards and benchmarking. fiscal incentives, grants, subsidies ▪ Compliance for NEW buildings - pending issue - should have been in force since 2018 (Regulation 7 of LN 47/18 - decision to set in force NOT yet taken) ▪ EPC certificates to be requested at Planning Authority application stages ▪ Government agency - tasked with development & management of schemes for energy performance of buildings, NOT BCA (similar to Paying Agency)	*EPC should always represent the "as built" situation and not simply the design rating scenario.*

▪ BCA Capacity - modelled, structured to permit monitoring and enforcement	

Other additional sources referring to energy use and buildings in Malta:

- Implementation of the EPBD in Malta – Status in December 2015[138].
- National Plan for Increasing the number of Nearly-Zero Energy Buildings in Malta [153].
- Europe's Buildings Under the Microscope: A country-by-country review of the energy performance of buildings[154].
- Policy measures addressing nearly zero energy buildings in the small island state of Malta[155]

Concept for a new EPC-system in Malta

Direct and indirect impacts of "energy use" to sustainability related aspects.

The impacts on the use of energy use in the building sector, are assessed in relation to a variety of criteria which relate to sustainability in the construction sector. The table refers to direct and indirect impacts for each of these attributes, summarised in the table:

Table 43: Sustainability related aspects and their direct/indirect impact

Sustainability Related Aspect	Direct	Indirect
Social aspects		
Thermal comfort in heating period		x
Thermal comfort in cooling period		x
Indoor air quality (influenced by ventilation rate)		x
Visual comfort (size of windows / lighting)		x
Acoustic comfort (noise from HVAC-systems)		x
Affordability (related to energy cost)		x
(Image of Individuals and institutions)		x
(user satisfaction)		x
Economic aspects		x
Construction cost		
Operational cost (important also for affordability)	x	
Economic value and value development of assets	x	
Economic values of companies and funds		x
Rent level	x	

Financial risk	x	
Funding	x	
Conditions of financing (impact on interest rate)	x	
Futureproofness of construction/property comp.		x
Income from energy generation (e.g. BIPV)	x	
External cost / damage cost	x	
Demand for low energy buildings		*x*
Demand for design and consultation service		*x*
Creation of jobs in industry and for designers(consult.)		*x*
Environmental aspects[4]		
Resource consumption/depletion (energy carrier)	x	
Resource consumption/depletion (other resources)	x	
Impact on global environment/climate (emissions)	x	
Impact on local environment (emissions)	x	
Avoided impacts by generation of renewable energy	x	
Technical aspects		
Peak load (heating period)	x	
Peak load (cooling period)	x	
Durability of envelope (moisture control/airtightness)		x
Deconstructability / recyclability of HVAC		x
Generated energy onside (eg BIPV)	x	
Policy related aspects		
Fulfilment of national targets (climate neutral Malta)	x	
Green public procurement		x

Main actors/stakeholders and target groups

The main stakeholder groups and the target groups which need to be addressed when considering an EPC framework for Malta need to be identified and addressed. A target group classification is presented hereunder:

[4] *During operation and also during life cycle (embodied energy)*

Table 44: Target Groups

Target Groups
Individual and institutional building owners
Individual and institutional investors
Developer[5]
Prefabricated houses industry[6]
Construction industry[7]
Real estate agent
Appraisal specialist
Financial institution
Insurance companies
Funding organisation
Sustainability assessor
Tenant / user / occupier
Visitor
Energy supplier
Designer (new construction)
Designer (major renovation)
National government
National institutions - economy
National institutions – construction/housing
National institutions - environment
National institutions - statistics

[5] *The market mainly refers to developers who purchase land, construct apartments and sell them generally. The rental market is on the increase also due to increasing number of foreigners working in Malta for temporary periods of a few years and the fact that locals start not managing to purchase property due to the increase in price of property (mainly due to the increase in cost of land).*

[6] *Not much of an industry locally.*

[7] *Most houses presently are apartments in blocks of loadbearing masonry construction with reinforced concrete roofs, or terraced houses using the seam construction method*

Interests of main target groups

The different target groups are interested in different categories and indicators. The table presents the interests of different target groups in relation to the indicators organised within main aspects namely: Social, Economic, Environmental, Technical and Policy Related.

Interest is represented as follows:

x - primary interest

(x) - possible interest

Blank - no interest

Table 45: Interests of main target groups

	Government (policy)	Government (owner)	Investor/ owner - private	Investor/ owner	Tenant/ user	Bank/ financial institution	Developer	Energy supplier
Social aspects								
Thermal comfort in heating period		(x)	(x)	(x)	x			
Thermal comfort in cooling period		(x)	(x)	(x)	x			
Indoor air quality		(x)	(x)	(x)	x			
Visual comfort (size of windows / lighting)		(x)	(x)	(x)	x			
Acoustic comfort (noise from HVAC-systems)		(x)	(x)	(x)	x			
Affordability (related to energy cost)					x			
(Image of Individuals and institutions)		x	x	x				
(user satisfaction)		(x)	(x)	(x)	x	(x)	(x)	
Economic aspects								
Construction cost		x	x	x		(x)	x	
Operational cost		x	x	x	x	(x)	(x)	
Economic value / value development		(x)	x	x		x		
Economic values of companies and funds								
Rent level					x	x		
Financial risk		x	x	x		x	x	
Funding			x	x			x	
Conditions of financing			x	x			x	
Future-proofness of companies				x				

Income from energy generation (e.g. BIPV)			x	x		x		
External cost / damage cost	x							
Environmental aspects								
Resource consumption/depletion (energy)	x	x		(x)				
Resource consumption/depletion (resources)	x	x		(x)				
Impact on global environment/climate	x	x		(x)		(x)	(x)	
Impact on local environment (emissions)	x	x		(x)				
Technical aspects								
Peak load (heating period)								X
Peak load (cooling period)								X
Durability of envelope		x	x	x		(x)		
Deconstructability/recyclability of HVAC		x	x	x				
Policy related aspects								
Fulfilment of national targets	x							
Green public procurement		x						

Concept for a new EPC framework

The table presents the key concepts for the development of a new structure for EPC covering key areas to support relevance and contextuality in Malta.

Key Concepts
Identification
Identification of building and building plot
Identification of the building owner from legal point of view
Identification of EPC-assessor
Identification of EPC (registration number)
Description of location
Climate zone
Solar radiation
Test reference year
Description of the building
Type and pattern of use / zones

Size and volume / stories
Number of units (e.g. flats)
Number of stories
Description of technical characteristics
Envelope (type of materials, U-values, orientation….)
HVAC-systems (year of production, efficiency, …..)
Additional building related equipment (elevator, ….)
Additional use related equipment (kitchen, refrigerator, ..)
Fulfilment of legal requirements
Energy performance
Solar protection
Moisture control
U-values of the envelope
Other legal requirements in Malta …
Energy demand (generic/specific conditions)
Heating
Cooling[8]
Hot water supply
Additional building related equipment
Additional user related equipment
Expected energy consumption (final energy)
… per type of use and energy carrier
… under average/specific conditions
… under specific scenarios (2, 4, 6, 8, xx inhabitants/flat)
Building integrated energy generation
Electricity from BIPV
Level of use within the property
Energy not used within the property

Expected energy cost

[8] *This component is particularly important in Malta. It is frequently argued that cooling needs are not taken well into consideration while the EPRDm and ISBEMmt methods adopted from dwellings and non-dwellings respectively, being an adaptation of nordic/ central european or rather UK methods, are more biased towards heating.*

Income
Possible income from exported energy
Achieved level of (thermal comfort)
… during heating period
… during cooling period
Environmental assessment[9]
Energy consumption – primary energy, non-renewable
Energy consumption – primary energy, renewable
Emissions to global environment (GWP 100)
Emissions to local environment
External cost / damage cost

Aggregated assessment results
Class of energy efficiency
Class of carbon performance / level of climate neutrality
Class of thermal quality of the envelope
Class of efficiency of HVAC-systems
Class of efficiency of user related equipment
Peak loads
… in heating period
… in a cooling period (average/heat waves)[10]

Concept for an EPC including stakeholder interests

The EPC framework recommendations are presented with the categories classified and related to interested stakeholders. Interest is represented as follows: x = primary interest, (x) = possible interest and Blank = no interest.

[9] *Subdivided into operational part and full life cycle including embodied energy and embodied emissions.*

[10] *Particularly relevant due to the high climatic conditions within the islands and its effect on the power distribution.*

Table 46: Concept of a proposed EPC based on stakeholder interest

	Government – environment	Government - statistics	Owner of all kind	User of all kind	Designer (next project)	Appraisal specialist	Energy supplier
Identification							
Identification of building and building plot		x					
Identification of the building owner		x					
Identification of EPC-assessor		x				(x)	
Identification of EPC (registration number)		x					
Description of location							
Climate zone		x			x		
Solar radiation					x		
Test reference year					x		
Description of the building							
Type and pattern of use / zones					x		
Size and volume / stories		x			x	x	
Number of units (e.g. flats)		x			x	x	
Number of stories		x			x		
Description of technical characteristics							
Envelope (type of materials, U-values, ….)					x	(x)	
HVAC-systems (year of production, efficiency,)					x	(x)	
Additional building related equipment (elevator)		(x)			x	(x)	(x)
Additional use related equipment (kitchen etc)		(x)					(x)
Fulfilment of legal requirements							
Energy performance	x	(x)	x		x	x	
Sun protection	x		x		x	(x)	
Moisture control	x		x		x	(x)	
U-values of the envelope …..	x		x		x	(x)	
Energy demand (generic/specific conditions)							
Heating	x	x		x	(x)		(x)
Cooling	x	x		x	(x)		(x)
Hot water supply	x	x		x	(x)		(x)
Additional building related equipment	x	x		x	(x)		(x)
Additional user related equipment	x	x		x			(x)
Expected energy consumption (final energy)							
… per type of use and energy carrier				x			(x)
… under average conditions and scenarios	x						

… under specific conditions and scenarios		x		x			(x)

	Government – environ.	Government - statistics	Owners – all types	Users – all types	Designer (next project)	Appraisal specialist	Energy supplier
Building integrated energy generation							
Electricity from BIPV	x	x			x	x	x
Level of self-use		x					
Exported energy		x				x	x
Avoided impacts from exported energy	x						
Expected energy cost		(x)		x		(x)	
Expected income from exported energy			x			(x)	
Achieved level of (thermal comfort)							
… during heating period				x		(x)	
… during cooling period				x		(x)	
Environmental assessment							
Energy consumption – primary energy, non ren.	x	x				(x)	
Energy consumption – primary energy, ren.	x	x					
Emissions to global environment	x	x				(x)	
Emissions to local environment	x	x				(x)	
External cost / damage cost	x						
Aggregated assessment results							
Class of energy efficiency	x			(x)	(x)	x	
Class of carbon performance	x			(x)	(x)	x	
Class of thermal quality of the envelope	x			(x)	(x)	x	
Class of efficiency of HVAC-systems	x			(x)	(x)	x	
Class of efficiency of user related equipment	(x)	(x)		x			(x)
Peak loads							
… in heating period							x
… in a cooling period (average / heat wave)							x
Building in use / real performance							
Real energy consumption	*x*	*x*		*x*		*x*	*x*
Certificates of inspection and maintenance						*x*	
Recommendations for retrofit			*x*			*x*	

Enhancing Energy Performance Certification and Sustainability in Malta: A Review and Proposed Transformations

This part presents a comprehensive review of existing gaps in Malta's building energy performance certification system and proposes key transformations for improvement. Specifically, it references the Building and Construction Authority's (BCA) regulations on Minimum Energy Performance Requirements in Buildings, as outlined in LN 47/2018 [156]. This transition from voluntary guidelines to mandatory application aims to elevate the energy efficiency standards of both existing retrofitted buildings and new constructions.

Moreover, the industry's utilization of calculation methodologies, which some key stakeholders argue need revision and updating, underscores the need for Energy Performance Certification (EPC). Stakeholders have consistently advocated for a broader sustainability approach beyond energy efficiency, emphasizing the importance of addressing cooling demands in Malta's hot and humid climate. This suggests the adoption of transient analysis methods over traditional steady-state assumptions, aligning with ISO 52000 requirements.

Furthermore, the paper highlights the significance of considering material properties, particularly the introduction of insulation in thermal conductivity assessments. However, it proposes that beyond assessing minimum thermal conductivity, other envelope properties should be evaluated to account for the effects of moisture diffusion through the building fabric envelope system.

Energy Performance Certification, Building Control Agency, Minimum Energy Performance Requirements, Sustainability, Transient Analysis, ISO 52000, Thermal Conductivity, Moisture Diffusion, Building Fabric Envelope System.

The EPC system should be better integrated with permitting process towards a wider and more effective implementation with a grading system towards classification. The latter can relate to tax incentives, government grants or other financial instruments addressing optimal interventions. Besides building passive features such as wall and roof insulation, there must be a wider appreciation of wellbeing also in the spirit of the New European Bauhaus[157], looking into indoor air quality. In general, the EPC application can lead to improved quality in buildings. It is also to be considered in the wider context of sustainability of buildings, beyond energy. Besides in the case of retrofit, interventions are to be seen in the wider sense with a consideration of material and building performance requirements.

For comprehensive insights into key recommendations for optimizing EPC software, please refer to the initial work package, specifically under the "Recommendations" section.

Existing Databases for Supporting Sustainability and Climate Change

This section includes reference to existing databases to support Sustainability but also Climate Change Adaptation as a relevant component in the drive towards decarbonisation. A short description of each database available is included.

MARIA/Eta High Resolution Atmospheric Forecasting System for the Central Mediterranean and Maltese Islands [158]

The Malta Blue Pages is an internet-based directory system for ocean and marine data and information, targeted to establish a single-point online reference, access, and repository for several marine data sources and descriptions in the field of marine environmental and oceanographic data in Malta.

MARIA/Wave forecasting system at IOI-Malta [159]

The operational wave forecasting system at the IOI-Malta Operational Centre, University of Malta uses the 3rd generation spectral wave model WAM Cycle 4 (Gunther et al, 1992). Originally developed by Hasselmann, the WAM model has been later extended by the WAMDI group (The WAM Development and Implementation Group).

Malta Shelf Hydrodynamical Model – ROSARIO [160]

The operational shelf scale forecasting system for the Malta Shelf Area runs in slave mode, through the daily re-initialization from the Sicily Channel Regional Model (SCRM) daily averaged forecast fields at day J (corresponding to Day 0 of the Malta shelf model) and the forcing at the lateral boundaries by SCRM fields in the subsequent days.

Malta GPS Wave Buoy Interface [161]

The deployment of the GPS directional wave buoy in Gozo forms part of the NEWS (Nearshore hazard monitoring and Early Warning System) project led by the Università degli Studi di Enna "Kore". The project is partially funded by ERDF funds through the Italia-Mala Interreg V-A Operational Programme (2014-2020). NEWS tackles the coastal erosion risks on the southern coast of Sicily and the Maltese Islands. Coasts are subjected to fast erosion due to natural and anthropic causes which involve the failure of cliffs, the triggering of localized erosions and the possibility of flooding. NEWS deals primarily with the modelling and monitoring of coastal risk processes, including the design of alert components against major risks. The system will make use of an integrated geophysical sensor network on land as well as a networked set of wave buoys installed offshore Sicily and the Maltese Islands.

Supporting Infrastructure and Training

The infrastructure to support sustainable development practices and training is necessary to ensure continued development in a sustainable construction industry.

Different platforms exist that provide tools on a national scale, ranging from base tools for planning to more advanced tools. The main educational institutions in Malta offer various courses addressing the theme. In addition, various initiatives exist to support continuous development.

Software, Hardware, and Scientific Facilities

The following is a List of existing scientific facilities in Malta *directly and indirectly* supporting the study and the implementation of climate change adaptation measures. The following includes a short description of each facility with website links.

Planning Authority

- Planning Authority Malta [162]
- Planning Applications, Malta [163]
- Geographic Information System: Map server of the Planning Authority, Malta [164]

The map server of the Planning Authority includes multiple data sets in a database and allows for access to planning, environmental, development boundaries, scheduling data, base data, enforcement, schemes and other data in a geographic information referenced system for the Maltese islands.

Lands Authority [165]

Lands Authority Plans and Survey Sheets for the Maltese islands.

CESBA e-learning platform – Sustainable Med Cities [166]

The CESBA MED project tested 10 case studies from all over Europe. A common sustainability assessment framework at urban and building scale was selected after the testing phase to support the development of energy efficiency plans for public buildings in the context of their surrounding neighbourhood.

Improving stakeholder skills by offering targeted training courses is an essential component of CESBA MED strategic overview. Two courses are offered according to the identified target groups and the two scales, building and urban. All training material is available in English and in another 5 languages (Italian, Spanish, French, Greek, Croatian).

Research and Training Facility – Water Tower managed by the University of Malta [167]

Water Tower Research and training station in new innovative durable materials for coastal environment, lifetime engineering, degradation of materials and structures, sensor monitoring station.

Research Facilities at the University of Malta

Various laboratories: Civil Engineering, Materials Engineering, Biology, Chemistry, other

Training and Skills

Training and skills were identified as major areas for action by different stakeholders. Reference was made to the two main educational institutions in Malta and to other private institutions. The following activities were highlighted as providing an important contribution:

Decarbonisation of the Construction Industry Course

Continuous Development Course for Engineers, Architects, EPC Auditors, Building Industry Stakeholders.

Course organised in multiple sessions, in person and online, during the period 2021 – to date, by the Building Industry Consultative Council.

CESBA e-learning platform – Sustainable Med Cities [168]

Two courses are offered according to the identified target groups and the two scales, building and urban. All training material is available in English and in other 5 languages (Italian, Spanish, French, Greek, Croatian).

Gaps and Recommendations

Significant gaps are evident upon reviewing the current regulatory landscape, guidelines, and standards applicable in the Maltese Islands. Additionally, several key recommendations emerge aimed at enhancing the sustainability of Malta's built environment. Various incentives are proposed to promote sustainable building practices, encompassing greening schemes and initiatives such as the 'Irrestawara Darek' scheme, 'Irrinova Darek', balcony restoration scheme, and other programs incentivizing the adoption of heat pumps, solar water heaters, solar PV panels, and renewable energy technologies.

Monitoring the effectiveness of these interventions is paramount, particularly for the authority responsible for subsidizing or financing such measures.

Furthermore, proposals gleaned from various forums and action plans encompass the following:

- Decoupling interest rates;
- Adjusting planning fees for sustainable building practices;
- Enhancing compliance methodologies post-implementation of works;
- Improving the delivery of sustainable buildings through a broader understanding of the significance of intervention quality;
- Introducing tools such as building files and passports to support these endeavors.

Environmental, social, and corporate governance (ESG)

The recognition of Environmental, Social, and Governance (ESG) priorities and the tangible steps taken by key stakeholders in the Maltese Islands hold the potential to rectify significant deficiencies in the sector. This proactive approach carries extensive implications, building upon prior efforts by various organizations, including governmental bodies, NGOs such as NTM and SBE Malta, as well as industry stakeholders, at both local and broader levels in preceding years.

Resources and Waste

Malta as an Island State with limited resources relies heavily on the importation of building materials. In this context, the conservation of resources is key towards achieving building sustainability and simultaneously addressing the waste issue due to the generation of large volumes of waste. In this context the planning requirement for provision of parking result in large volumes of excavated material for disposal. This suggests a wider review of the current practice towards a more sustainable approach beyond the waste management sector. Key tools to address the gaps are presented in the SM810 and draft SM820 standards, which include:

- The requirement for a waste catalogue;
- Implementation of classification of aggregate;
- Initiatives for upscaling of elements and products at end-of-life;
- Short term objectives and Long-term objectives;
- Alternative excavation;
- Design for deconstruction.

Construction Products Regulations – Gaps and Recommendations

A notable deficiency within the construction industry pertains to the Construction Products Directive and its application and enforcement in Malta, which has broader implications for construction products and systems. A more extensive enforcement is anticipated to enhance safety in construction and indirectly elevate the quality of construction materials, products, and building elements and systems. Although the Construction Products Regulations (CPR) [169]have been transposed into National Legislation[170], the adoption of CE marking and the declaration of performance, coupled with effective market surveillance focused on key building materials and products, necessitates further implementation on a national scale. The CPR and the utilization of CE marking play a crucial role in the advancement and execution of sustainable construction systems reliant on products with known origin and performance. This pivotal measure should be viewed within the broader context of construction in Malta, alongside the evolving Construction Products Regulations of the European Union, which entail significant developments and updates.

Energy Performance Certification – Gaps and Recommendations

The report highlights deficiencies in Malta's building energy performance certification, offering crucial recommendations for a broader sustainability strategy, including a comprehensive assessment of sustainability practices across the Maltese islands.

For comprehensive insights into key recommendations for optimizing EPC software, please refer to the initial work package, specifically under the "Recommendations" section.

Comprehensive strategies – Recommendations

While this report underscores the significance of energy efficiency in buildings, it prioritizes the enhancement of fundamental building standards, construction practices, and materials, as well as improvements in construction work practices. While these aspects may appear separate from energy efficiency, they are essential prerequisites in the local context, where there are well-documented deficiencies in material quality, construction systems, and structures.

This emphasis is particularly relevant considering trends observed in other countries like Italy, where the retrofitting strategy for buildings encompasses structural and seismic retrofitting to ensure the sustainability of interventions. This becomes even more critical considering the unsustainable approaches that have prevailed in recent years, where renewable energy has been introduced into buildings without first addressing structural deficiencies and implementing energy efficiency measures. A truly sustainable approach to green buildings necessitates a comprehensive retrofitting strategy for existing building stock, which includes both structural and energy retrofitting to achieve sustainability objectives.

Currently, there are gaps in the implementation of a piecemeal approach, where actions are fragmented and often focus solely on energy efficiency without first addressing structural and fabric retrofitting. Addressing this gap requires a comprehensive approach to upgrading and retrofitting buildings. Building sustainability can only be achieved through approaches that prioritize durability and adhere to circularity.

Building Certification Methods

The implementation of building sustainability ratings marks a crucial stride towards embracing green solutions, technologies, and sustainable practices across the entire lifecycle of a building, spanning from design and construction to management and eventual decommissioning. Various green certification methods, such as LEED [171]and BREEAM [172], have been employed in Malta to evaluate the sustainability of different buildings. Additionally, tools like SB Tool and CESBA Tool have been utilized to assess specific sectors at both urban and building scales.

However, a significant gap persists in establishing national parameters and limit values due to insufficient data across various sectors. Efforts to address this gap have been initiated through projects like CESBA, where issues and indicators have been identified based on available data sources and stakeholder consultations. The absence of national standards and building regulations further exacerbates this challenge within the local context.

This approach aims to bridge existing gaps, particularly concerning the setting of limits specific to the Maltese Islands' climate and context, and prioritizing indicators critical to the local scenario. For instance, the sourcing of construction materials poses a challenge as most materials are imported, highlighting the importance of water conservation in the water-scarce Maltese context.

Furthermore, extending the application of sustainability tools to the broader urban context is imperative, ensuring that sustainability considerations are not limited to large buildings prioritizing corporate image. By addressing the entire building stock, both short-term and long-term benefits can be realized, effectively tackling key sustainability issues in building design, construction, and retrofitting.

Proposals have emerged in various forums advocating for green certifications or sustainability audits as mandatory activities for developments exceeding 500m^2 of floor area, reflecting a growing recognition of the importance of sustainability in development practices.

For a deeper understanding of practical Building Certification methods, please consult the initial work package of this document, particularly within the "Building Certification Process" section.

Conclusion

In conclusion, the establishment of robust building regulations and policies is paramount for the Maltese islands to set clear national standards and address critical aspects of construction, encompassing excavation, demolition, building materials, energy efficiency measures, renewable energy systems, building management systems, and essential criteria like fire safety and accessibility.

There is a widespread consensus among various stakeholders regarding the urgent necessity of a regulatory framework for building construction. While commendable progress has been made in recent years, including the development of new regulations for excavation, demolition, and construction by the Building Industry Consultative Council (BICC), which have undergone consultation and are proposed for publication, their actual implementation remains pending. This delay in the publication of regulations and codes creates a significant void in the building sector, greatly impacting sustainability performance.

WP3 (PART 2): Sustainable Financing

Introduction

The *Investment Report 2022/2023* issued by the European Investment Bank (EIB) [173]states that finance plays a pivotal role in mobilising capital for green investment and in making the European economy more sustainable. Indeed, this report suggests that the stability of the financial system and its capacity to fund the green transition are interlinked, and that the financial system is a catalyst for green investment, with the decision of investors fund to fund "green" or "brown" industries having a profound effect on the trajectory of carbon emissions.

This report suggests that banks with higher profitability and better asset quality are more likely to fund firms that invest in climate change mitigation and adaptation. Nonetheless, public funds will continue to play an important role in unlocking private investment to support the energy transition, via existing programmes under the national public investment schemes, NextGenerationEU [174] and the multiannual financial framework. However, most of the necessary investments will need to come from private funds.

Fortunately, sustainable finance activities have increased significantly over the last five years, quantitatively and qualitatively, with activities ranging from green debt to equity fundraising for green-tech firms and technologies, to mitigate or reverse the impact of human activity on the environment.

As a leading global Bank, HSBC is committed to sustainable growth, and is aware that its business has an impact on people all over the world. Indeed, the Group Chief Executive Noel Quinn has declared that as a bank, it aims to power new solutions to the climate crisis and to support the transition to a low- carbon future. In its **Financed Emissions Methodology Update** [175], published in February 2024, the transition to net zero is recognised as one the of biggest challenges for this generation. The report acknowledges that the ability to meet the bank's net zero ambition – namely to align the financed emissions of its portfolio to net zero by 2050, and to become net zero in its operations and supply chain by 2030 – relies on the pace of change taking place in the real economy and the actions taken about a broad set of stakeholders, including policy makers.

On a practical level, HSBC has embarked on several projects globally in the area of decarbonisation, with its focus ranging on decarbonisation from the power and transport sector to the heat sector, with the latter being referred to as the “third frontier”. Over two years, the financial sector developed an industry-wide approach which is premised on banks partnering with customers to finance their transition. So, the money increasingly stands ready. Deploying it at the scale required to fund the net zero transition is the next challenge. By partnering with the energy sector, banks can facilitate the capital investment needed to reduce emissions at scale.

Within this context, and as part of the efforts aimed at analysing the market for Green Buildings in Malta, a desk-based research exercise was carried out to look at sustainable financing mechanisms within and outside of Europe, as well as those existing in Malta. The research sought to examine the different forms of assistance being provided, whether repayable or not, and whether any of such mechanisms could be reproduced in a local context. The aim is to provide with policy makers and market leaders concrete examples and proposals for green building finance products.

The current scenario [176]shows that after years of stagnation, the overall investment in energy efficiency measures in the buildings sector has increased globally by more than 15% in 2021. This is a level of growth that, if sustained, would be compatible with the levels of the Net Zero Scenario (11% per year). However, the growth in investment has already started slowing down in the first half of 2022, as construction and material costs reached all-time highs, and the direct stimuli that incentivised energy efficiency investment, start winding down in several countries in Europe.

Furthermore, despite this new interest from banks, demand for energy efficiency loans is still weak in many European countries for several reasons, namely that:

- Companies and individuals are often not aware of the renovations that can save energy and money, so such projects are low in priority;
- The energy savings documentation required to qualify for energy efficiency financing, is often not available or is insufficient to support a loan application;
- Renovation costs for energy efficiency are too expensive for many households and companies;
- The path to financing is too long and cumbersome.

As highlighted in the Bloomberg article *Financing the Net Zero Transition* [177], the global transition to a net zero economy can only be possible with huge financial support and multilateral cooperation. According to OECD estimates, an annual investment $1,000 per every person on the planet**,** or $6.9 trillion, is needed to partly solve the climate problem with low-carbon, climate-resilient infrastructure [178]. While these figures make for heavy reading, it must also be acknowledged that the will to move towards carbon-neutrality, and even carbon-negativity, by some leading technology firms, such as Microsoft and Google, exists. Furthermore, the United Nations' Race to Zero initiative has also managed to secure a commitment by nearly 1,700 companies, amongst which the largest emitters, to half their emissions by 2030 and to achieve net zero emissions status by 2050.

However, making these commitments a reality is a far more complex process. Peter Gassman, Global Strategy Leader and Global ESG Leader and Partner within PWC Germany has declared that, to date, the global economy is nowhere near to its targets, and that Nations cannot meet their net zero targets without transforming their economies and the industries within them; to do this, leaders in each sector would need to collaborate with each other.

This same article mentions that Green Bonds, designated for specific climate and environment-related projects, have developed rapidly since the first green bond was issued by the EIB in 2007. While rising regulatory scrutiny has started to temper uptake in the second half of 2021, their growth has risen in step with the growing awareness and consciousness around climate change, as well as attempts to build a low-carbon future.

In the below sections of this report, a number of existing instruments in the United States and Europe will be presented and followed by an analysis of the situation in Malta. The report will focus predominantly on repayable assistance – as opposed to grants – as the latter is not considered within the scope of this exercise.

Financing Mechanisms across different countries

On-Bill Financing in the United States

An instrument that is offered in the USA is On-Bill Financing for Energy Efficiency [179] , which is offered by utility companies which pair loan repayments with monthly energy bills to make it easier for homeowners and businesses to invest in energy efficiency improvements for their properties. The system is designed to facilitate access to finance for EE measures through repayments of EE loans through the monthly repayments on their energy bill.

The instrument proposes two types of options, namely:

- On-bill financing: namely the provision of funds directly by the utility company to the property owner to carry out EE upgrades, with the customer repaying the utility through their monthly energy bill;
- On-bill repayments: this would be a very similar system, but instead of the funds being provided by the utility company, this would be provided by a third-party lender, such as a commercial bank.

The main advantage to customers through this system is that when they pay the loan back through their utility bill, the monthly repayments will be lower than the savings from the EE projects, resulting in net savings from day one. Furthermore, there is the possibility to transfer the remainder of the loan, if the property is sold, to the new property owner, with said buyer taking on the loan repayments as part of their own utility bill. Even if this is not possible, since energy-efficient homes tend to sell for a higher price, the investments would still result in net profit for the original owner.

Utilities in California, Connecticut, Hawaii, Kansas, and New York are among many that offer on-bill programmes of some kind. Some utilities offer programs exclusively for commercial or residential properties, while others have broader eligibility criteria.

The Green Deal in the United Kingdom

A similar instrument was piloted in the United Kingdom, called the Green Deal [180], being an 'on-bill' financing mechanism secured against the electricity meter. However, public investment was withdrawn after homeowner take-up fell short of expectations.

The scheme is currently under review and still available to private finance providers wishing to enter the market. Indeed, the Renewable Heat Incentive offers financial support for seven years to owner-occupiers adopting a renewable heating system. The government's election manifesto committed to a new Home Upgrades Grant scheme of £2.5 billion over five years from 2020/21. This would focus on subsidising 'whole-house' retrofits for low-income households. Eligible households include owner-occupiers living in F- and G-rated properties, in deprived areas. Whilst at an early stage, the private sector is starting to develop financial products to help owner-occupiers retrofit their properties. Green Mortgages are available from Barclays, Nationwide and Ecology Building Society, whilst the Energy Efficient Mortgage Initiative aims to develop a pan-European model for energy-efficient mortgages.

Furthermore, an energy efficiency policy is being rolled out in the UK (except for Northern Ireland) through the Energy Company Obligation [181]. Delivered by energy suppliers and worth £380 million in 2019, it primarily funds insulation measures and efficient gas boiler replacements, with a focus on lowering heating costs for low income and vulnerable households across all tenures. In 2019 only, it helped 78,000 owner-occupied households.

The ECO scheme works by placing a Home Heating Cost Reduction Obligation (HHCRO) on medium and large energy suppliers. Under HHCRO, suppliers were obliged to promote measures that improve the ability of low-income, fuel-poor and vulnerable households to heat their homes. This includes actions that result in reduced energy usage, such as installing insulation or upgrading a heating system. The overall target for these measures is divided between suppliers based on their relative share of the domestic gas and electricity market.

Another interesting instrument that was deployed in the UK is the Joint European Support for Sustainable Investment in City Areas (JESSICA), which is an initiative developed by the European

Commission and the European Investment Bank (EIB) [182]in collaboration with the Council of Europe Development Bank.

The EIB is the biggest multilateral financial institution in the world and one of the largest providers of climate finance and support projects that promote the EU's objectives. As the EU's climate bank, the EIB takes action to preserve natural resources and protect the environment for future generations, investing in projects in over 160 countries by providing lending and advisory expertise. The EIB support acts as a catalyst to mobilise private finance, by encouraging other public and private investors to match their long-term investments. The EIB finances projects that:

- **Unlock energy efficiency:** including retrofitting and expansion of existing social and urban infrastructure and services.
- **Support the decarbonisation of energy supply:** finance for renewable energy projects in Europe and beyond – **onshore** and offshore wind farms, solar, hydropower, geothermal and solid biomass projects, among others – and the development of the enabling infrastructure.
- **Provide sustainable energy project advice:** Many cities and regions lack the necessary technical expertise and organisational capacity to implement large energy efficiency and renewable energy projects.

The JESSICA initiative, like the financial Instruments deployed in Malta and other EU Member States (MSs), allow MSs to make contributions from their Structural Fund Programmes, along with funding from other public and/or private sources towards Urban Development Funds (UDFs). The UDFs would then invest these monies, in the form of equity, loan and/or guarantee in urban development projects.

One of these UDFs is the London Energy Efficiency Fund (LEEF) which provided debt financing to support EE measures in the 72 buildings across the following projects:

- **Tate Modern:** retrofit and installation of energy-saving measures, including waste heat recovery from the substation;
- **LB Croydon:** energy efficiency measures in several of the Council’s properties, including 50 primary schools and a 1960s art centre;
- **Salters Hall:** energy efficiency measures across two sites;

- **St George's:** energy efficiency measures across hospital properties and installation of Combined Heat and Power;
- **LB Hackney:** installation of communal heating systems for ten tower blocks; and
- **Greenwich Peninsula:** construction of an energy centre with a gas CHP and boiler, which will provide low carbon energy for properties on the peninsular.

Another UDF, namely the Housing Finance Corporation Limited (THFC) similarly invested in three Registered Providers of social housing to support the refurbishment of over 2,500 properties to make them more environmentally friendly.

JESSICA and EE in Lithuania

Lithuania has similarly made use of the JESSICA instrument, by which a combination of EU and National Funding created a €227 million portfolio of loans, deployed through three Commercial Banks, acting as Financial Intermediaries. The loans provided through this instrument included the below preferential conditions that were made possible through the public fund injection that served as a guarantee for possible loan defaults:

- 100% grant to prepare renovation documentation;
- 15% loan rebate for where minimum energy efficiency level is met (class D level, 20% reduction);
- Exceptional 100% subsidy on all expenses for low-income persons;
- Loan maturity of up to 20 years;
- 3% interest rate fixed for the entire loan period;
- Deposit limited to 5%;
- Maximum monthly instalment determined for each multi-apartment building;
- No loan insurance requirements;
- No collateral requirements; and
- Two-year moratorium during the construction period.

This initiative was followed by the ambitious Energy Efficiency (EE) renovation programme, which uses ERDF financial instruments, more than 3,000 multi-apartment buildings have been renovated so far in the country, while more than 1,000 projects are in various stages of preparation. This Renovation Programme, which started in 2004, is part of the country's **National Energy Plan** which is aligned with the and Renovation Wave strategies. It uses **ERDF financial instruments** with an aim to mobilise the finance necessary to achieve the target of **renovating all multi-apartment buildings** to modern energy efficiency standards by 2050. Following the renovations, the aim of these investments is to increase energy efficiency by **more than 60% on average** and decrease CO2 emissions **by more than 80%**.

Eco-Loan Programme in France

In France, an eco-loan programme led by the *Agence de l'Environnement et de la Maitrise de l-Energie* (ADEME) provided interest free loans of up to €30,000 aimed at improving energy efficiency of one's property. Desk based research [183] has shown that these loans seemed to be targeted specifically towards retrofit of existing properties, since their applicability extends only to properties built before January 1990.

The loan repayment period was set at ten years but could be extended up to fifteen years if deemed necessary due to the extent of both the building work and the loan amount. Eligible expenditure under these loans included energy saving installations and renovations such as:

- loft insulation;
- the fitting of double-glazed windows and doors;
- solar panels;
- green heating systems, rainwater harvest systems; and
- sewage systems.

Prior to applying for such a loan, a thermal survey was required on the property for the loan to be granted based on Bills of Quantity (BoQs) from a registered builder, thus excluding DIY projects.

Promotional Loans and Positive Incentive Loans in Germany

In Germany, the financing of sustainable projects is predominantly led by the federal government and/or federal States in conjunction with the European Union through targeted funding programmes. Loans are provided by the Development Banks within the individual states and by Kreditanstalt für

Wiederaufbau (KfW), which seeks to support private individuals, businesses and public organisations with promotional loans and grants, through its financing partners. These include Sparkasse savings banks, Volks- and Raffeisenbank cooperative banks, and local commercial banks.

By way of example, KfW IPEX-Bank [184]provides financing to support the German and European economies and for environmentally and climate-friendly investments. Together with the German and European export sectors and its global corporate customers, KfW IPEX-Bank aides the transition to a sustainable society in all three dimensions – economically, environmentally, and socially – in Germany, Europe and throughout the world. It promotes technological transformation by developing suitable financing solutions with the aim of improving and securing livelihoods and quality of life for future generations.

When it comes to the financing of buildings, Green Loans by KfW IPEX-Bank can be given if the following criteria are met:

- for replacement investments, proof of absolute energy/CO2e savings or proof of specific energy/CO2e emission savings of at least 20% must be provided in a before/after comparison; or
- for new investments, proof of energy/CO2e emissions savings of at least 15% compared with the national sector average of the installed capacity must be provided;
- In both cases: compliance with (inter)national or regional standards or presentation of corresponding certificates (as per the GLP).

On the other hand, positive incentive loans follow a completely different approach and are used in Germany to generate general corporate financing without being earmarked for any specific purpose. The interest rate of the loan changes depending on how sustainable the company acts overall, meaning that the more sustainable a company is, the lower the interest rate, hence, “positive incentive.”

With positive incentive loans, the market for sustainable financing provided companies with the opportunity to specify clearly definable green projects for themselves. However, to date, there are only a few transactions on the market that have been structured in a similar way – one of them being the positive incentive loan agreed between Voith and LBBW in January 2019 [185], where the amount of the guaranteed commission depends on Voith's sustainability rating.

Green Mortgages and shared performance improvement goals in Italy

An example of Green Finance in Italy is that provided by Intesa Sanpaolo [186], which offers more favourable interest rates to those customers that seek to purchase or refurbish their home with a view towards increased energy efficiency. The bank also offers a free energy certification service in the case of building renovations with the improvement of at least one energy classification as well as optional green services offered by partner companies to achieve the said improvement, such as energy audits, energy provision consultancy and quotations and favourable lending rates for the acquisition of appliances.

Regarding small and medium sized enterprises, Intesa Sanpaolo launched a loan that revolves around the idea of sharing of sustainability performance improvement goals by businesses, through specific commitments taken with the Bank via specific KPIs subject to annual monitoring. High performing companies are rewarded by rate reductions and special loan conditions. In 2022, around 1,360 projects with an overall value of approximately €2.2 billion were funded through this mechanism, showing that it was very successful with SMEs.

The local context

The local scenario has for many years been characterised by a strong grant environment, which various forms of non-repayable assistance, such as part-financed reimbursements and tax credits, dominating the access to finance landscape until the introduction of the JEREMIE Financial Instrument in 2010. This instrument, introduced to the market the possibility of repayable assistance in the form of low interest, low collateral loans, which are guaranteed by the European Regional Development Funds (ERDF) provided clients, especially SMEs, with a taste of financial aid with less bureaucracy and increased flexibility.

The JEREMIE Financial Instrument, which was a First Loss Portfolio Guarantee (FLPG) instrument implemented by the Maltese Government and the European Investment Fund was – at the time a surprising success, and was then emulated by the SME Initiative, a joint initiative between the

European Commission, the European Investment Fund, and the Maltese Government. The SME Initiative, which worked very similarly to JEREMIE, created a portfolio of loans at low interest and no collateral that would finance capital investment and – because of the COVID-19 pandemic – working capital relief. Just like its predecessor, the loan products resulting from this instrument were extremely successful, with subsequent ERDF financed top-ups to the Financial Instrument resulting in a larger portfolio of loans that was repeatedly fully committed.

Within this context, the Maltese Government decided to participate in a third joint initiative between the same parties, this time with a Financial Instrument, the Smart Financing for Smart Buildings (SFSB) Initiative which was launched in 2018 with the aim is to make investments in energy efficiency projects in residential buildings more attractive to private investors, through the intelligent use of EU grants as a guarantee to create Green Loans at very favourable conditions for the Maltese market.

The SFSB, which was rebranded as Energy Efficiency and Renewable Energy (EERE-Malta), is also an FLPG, but includes an Interest Rate Subsidy (IRS) that acts as a grant element for the end customer. This blended instrument has been implemented on the ground over the past years by two commercial banks, namely Bank of Valletta and APS Bank, acting as Financial Intermediaries and providing loans for investments related to the building envelope and investments related to the building system. Notwithstanding the success of the abovementioned instruments, the EERE-Malta gained limited traction in the beginning resulting the Financial Intermediaries broadening the eligibility requirements and revising the loan conditions to make them even more favourable and attractive.

- The instrument as implemented in April 2023, provided loans with the below conditions:
- **Bank of Valletta Business Energy Loan:** a subsidised (resulting in an interest free) loan for ten years for a maximum term of ten years, with a maximum loan amount of €750,000 and a minimum contribution of 20%
- **Bank of Valletta Personal Energy Loan**: a subsidized (resulting in an interest free) for ten years for a maximum term of 15 years, followed by a 2.5% variable interest rate for the remaining term. No security or contribution is required.
- **APS Green Finance:** a subsidized (resulting in an interest free) for the first ten years for a maximum of 15 years, followed by a 2.05% variable interest rate for rate for the remaining term. Minimum contribution ranges between 0 – 20%, case dependent.

In addition, together with these loans, a Climate Impact Calculator was developed by the EIB [187] to assist possible candidates for the EERE Malta instrument, to evaluate the climate impact of their planned investment. The impact is evaluated by providing estimates in terms of energy savings, Greenhouse Gas (GHG) emission reductions, renewable energy capacity added and, perhaps most impactfully, financial savings.

Nonetheless, the anticipated interest was limited in the first years of their launch, mostly because the original interest rates were not deemed to be favourable enough, and the eligible expenditure was hindered by restrictions imposed by State Aid regulations, such as those impeding enterprises from jointly benefitting from these Green Loans and the Feed-In Tariff upon the installation of Photovoltaic Systems. Meanwhile, the further decrease in interest rates, have then resulted in actual terms as zero interest loans through the application of an Interest Rate Subsidy and, as a result, a higher take up by end of 2023. There is ongoing dialogue and plans for the facilitation of a new Energy Efficiency instrument similar to EERE for 2024 and beyond as right now there exists a gap when it comes to this financial instrument.

Further to the above, other Green Products are available on the Maltese market.

The HSBC Energy Efficiency Loan may be used by personal customers to finance several environmentally friendly products and services including among others:

- Renewable energy, primarily the installation of solar water heaters and photovoltaic panels;
- Green buildings and solutions, including thermal insulation and double glazing; and
- Clean transportation, including financing the purchase of hybrid and electric cars.

Green Loans for commercial customers are also available to HSBC's commercial customers in Malta. Green Loans are made available for the finance or refinance, in whole or in part, of new or existing eligible Green Projects. These are similar to a normal corporate loan but need to follow the Green Loans Principles (GLPs), which were launched by the Loan Market Association in March 2018. They are closely aligned with the Green Bond Principles (GBPs).

HSBC's commercial customers can also be provided with Green Trade Finance facilities, which support eligible environmentally sustainable trade activities, and promote underlying activities that provide clear environmental benefits that can be assessed, and where feasible, quantified, measured, and reported on. Examples of applicable scenarios for eligible financing are among others:

- Sourcing eco-friendly raw materials.
- Procuring eco-friendly machinery/ goods/ services.
- Manufacturing eco-friendly products.
- Trading eco-friendly commodities.
- Services/expenditures to and for green projects.

HSBC also offers Sustainability Linked Loans, which are similar to normal corporate loans but should follow the Sustainability Linked Loan Principles (SLLPs), which are voluntary recommended guidelines issued by the Loan Market Association (LMA). They can take the form of any type of loan instrument and/or contingent facilities which incentivise the borrowers to achieve ambitious, pre-determined sustainability performance targets by linking the interest rate to achievement of such targets.

Sustainable Trade Instruments complete HSBC's offering in the sustainable space. The Sustainable Trade Instruments include guarantees, letters of credit, or standby letters of credit issued under a sustainable trade facility made available to corporates to facilitate environmentally and/or socially sustainable economic activities (e.g., supply, production, of sustainable goods/services or support of a sustainable project).

Finally, it is worth highlighting HSBC's capabilities in terms of the extensive and various research material that the bank, with its global presence, may offer to its corporate clients. HSBC Malta's website gives corporates access to information in the green or ESG space [188] . In addition, the bank can offer live market research related to specific sectors and industries prepared by its international network of economists and markets analysts. Global Market Research [189] is a very valuable instrument which corporates find extremely useful to guide strategic decisions.

Notwithstanding the efforts being made on a local level, a report on the Energy Performance Buildings Directive commissioned by the Malta Business Bureau to Deloitte [190] states that, it is generally perceived that the schemes and incentives currently in place are unlikely to be sufficient to meet the magnitude of financing requirements expected for a successful green transition and that are required under the revised Energy Performance Building Directive. Meanwhile, the discussions surrounding the revised EPBD have further raised the ambition and targets which buildings must meet, potentially requiring an even larger investment effort. It is for this reason that the report argues for alternative support measures to be developed to fill the gaps where necessary. These would not replace existing measures, but rather complement them and provide additional options appropriate to business needs.

Other Financial Instruments

Financing the transition to a circular, carbon neutral society, in its many aspects, is crucial to the success of the national goal of achieving climate neutrality by 2050. It is necessary to ensure that climate policy is financed in a sustainable manner and that it is implemented efficiently, and in line with the country's long-term objectives, avoiding financing investments that are not in line with this objective and enhancing the creation of new clusters in the country. For this reason, it is essential to foster the development of a favourable environment for sustainable financing and greater involvement of the financial system.

European Financial Instruments:

- The 2021-2027 Multiannual Financial Framework [191]
- Action Plan for Financing Sustainable Growth [192]
- LIFE Program
- EIF InvestEU Guarantees [193]
- The Connecting Europe Facility (CEF) [194]
- The European Regional Development Fund [195]
- Horizon 2020 and the subsequent Horizon Europe, Innovation Fund [196]

National Financing Instruments

The national climate policy also benefits from the allocation of an important group of revenues generated by the climate policies themselves. One would need to identify any possibly national financing instruments readily available which embodies decarbonisation of the economy as one of the structuring areas.

One should consider the use of revenue generated from auctioning of EU ETS allowances, also considering the list of areas identified in the EU ETS Directive (Article 10(3)) including point "(h) measures intended to improve energy efficiency, district heating systems and insulation, or to provide financial support in order to address social aspects in lower- and middle-income households". [197]

Other instruments are enabled through the Malta Development Bank (MDB) in association with the European investment bank. One of such initiatives includes the MBIL Climate Action Loan . In 2023, the MDB signed an agreement with the European Investment Bank (EIB) through which the Bank will access financing, which will be directed to the local private and public sector for projects that promote multiple sustainable initiatives of which include, sustainable mobility, renewable energy production, energy efficiency and recycling.

There also exist EU funded aid schemes specifically for retrofitting of buildings under the Recovery and Resilience Plan for Malta. These are grants targeting the renovation of private sector buildings for retrofitting and energy efficiency (including commercial/non-residential buildings).

With the launch of the new GBER, a new article addressing retrofitting actions was published, (Art. 38 (a)) [198], and a new scheme with more favourable rates of assistance, in line with this new article, shall be published soon and fresh call/s launched subsequently.

It is imperative that Governments actively support the transition towards sustainability, alongside banks and financial institutions. Government leadership is essential in catalysing this transition, both through regulatory frameworks and financial support mechanisms. National and global leadership is required to drive this green transition across sectors.

Governments have a range of policy tools and financing options at their disposal to facilitate the transformation of energy and industrial systems, enhance energy efficiency, address environmental challenges, and conserve natural resources. This dual approach involves implementing minimum mandatory requirements, such as the introduction of initiatives like Guidance F and beyond. For

instance, governments could consider mandating green certification for buildings larger than 500m2, which could unlock various financial and policy incentives, including expedited permitting procedures. Another strategy is for governments to provide comprehensive financial packages, acting as a one-stop shop, to facilitate access to renovation and green building practices for households and businesses. Currently, individuals and businesses often face challenges navigating the various government initiatives available. Streamlining grants and schemes would increase uptake and effectiveness.
Additionally, governments can offer subsidies and grants to research institutions, academia, and private R&D organizations to stimulate innovation and develop transformative technologies. Areas of focus could include renewable energy, sustainable building materials, waste management, and energy efficiency. By fostering innovation in these areas, governments can accelerate the transition towards a greener economy.

One other element that should be considered for a fair and just transition is the need to ensure that low-income households may also participate in the decarbonisation of Malta's economy and can also benefit from such decarbonisation.

The Building Scoping Paper published by the Climate Policy Initiative [199]on the Financing of Net Zero Carbon Buildings through the use of Financial Instruments presents both traditional instruments, such as equipment leases, mortgages, and bonds, as well as specialised mechanisms that utilise the cost savings energy efficiency such as on-bill repayment, energy service contracts, and property assessed clean energy loans.

This states that while traditional instruments like bonds and commercial debt can work at scale, on their own they have been unable to help shift the market to lower carbon buildings. Conversely, specialised instruments explicitly targeting net zero buildings, have had difficulty scaling and reaching lower-income households. While several policies exist internationally to support net zero carbon buildings, such as, green building labelling, energy efficiency building codes, and equipment performance standards, these policies are not widespread, especially in low and middle-income countries with the greatest building stock growth, that often lack ambition. The success of policies is dependent on the capacity to implement and enforce them, and a construction sector that can deliver low carbon buildings.

Thus, what is needed is a successful convergence of financial Instruments and policies that can be used by Governments and financial institutions to shift investment to net zero carbon buildings. The Building Scoping Paper identifies eleven financial instrument categories depicted in the figure below which acknowledges that each instrument faces distinct challenges to scaling support for net zero carbon buildings. Indeed, the authors explain that while traditional instruments need to focus on improving the net zero criteria, many specialized instruments face scalability challenges.

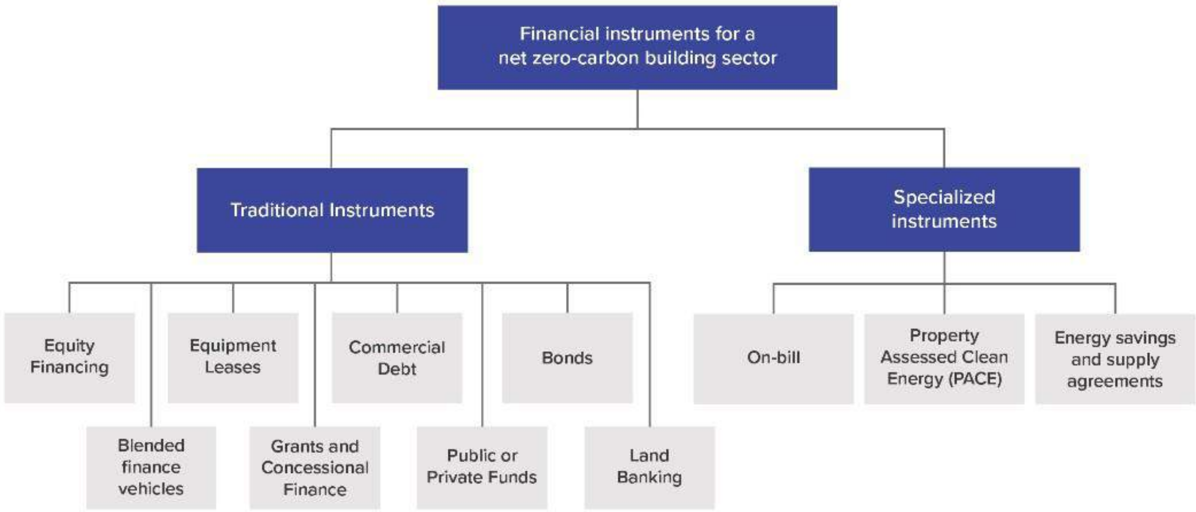


Figure 47: Organigram of different financial instruments for a net zero carbon building sector [199]

Traditional Instruments

Traditional instruments that are used to finance buildings generally are also suitable for financing zero carbon buildings. These include equity and self-financing, equipment leases, commercial debt, and bonds. Indeed, traditional instruments, incorporated in the traditional commercial and banking instruments have served a transition to low-carbon buildings, such as traditional mortgages that have enabled EE measures in buildings, without being specifically designed for this purpose. However, the paper also acknowledges that a traditional mortgage system that finances low and high-carbon buildings interchangeably, with the same conditions, does not provide an incentive for customers to invest in buying/constructing green buildings, which in turn prevents financial players from identifying green opportunities and monitor low-carbon projects.

A possible solution to this state of affairs, presented by the authors is the creation of green equivalents to these instruments that provide tailored terms to projects that comply with various sustainable requirements with lower-cost debt, such as:

- Green or Energy Efficient (EE) mortgages schemes with discounted rates, to better performing buildings and additional 'Energy Efficiency improvement' loans that can be attached to a green mortgage to cover expenditure on energy efficiency measures.
- Solar Leases which would allow businesses and households to install photovoltaic solar panels on their properties with no upfront cost while paying monthly rents for the panels. Depending on whether it is an operating or capital lease, the customer could then buy the equipment at a reduced price at the end of the contract.

On a local level, it seems that the current approach, namely that of Green Loans which are guaranteed through Public (EU Funds) which does allow for low interest rates, minimum collateral requirements and an Interest Subsidy that in practice nullifies the interest is starting to generate interest and take up. Nevertheless, it can also be partnered up, as highlighted in the case study by Italy, with incentives that reward Energy Efficient investments over others, providing ancillary products and services as part of the loan product offered by the lending institution.

Specialised Instruments

Specialized Instruments are a class of financing that seeks to harness the ability of buildings to produce and retain energy in a more sustainable way. These mechanisms source their financial sustainability in the simple concept that better performing buildings require, less external energy to operate. Typically, these products would seek long-term profitability directly through energy efficiency and onsite energy generation measures that reduce utility bills.

As explained in the paper, and as referenced earlier in this report through a case study of the USA, the simplest example of such a specialised instrument would be a structure of on-bill financing and repayment (OBF and OBR), i.e., the utility or a third-party lender (such as a commercial bank) would pay the upfront cost of installing energy efficiency measures in a building. Customers would then repay the lender through their utility bills.

An example of a more complex system, which is in place is the Energy Performance Contracting (EPC, or ESPC in the U.S.). This arrangement directly involves the energy service companies (ESCOs) in charge of project implementation and potentially transfers them the performance risk [200].

Other examples presented by the authors are the so-called Property Assessed Clean Energy (PACE) programmes, which allow property owners to finance the up-front costs to then repay them back over time through a property tax bill. Such assessments would be attached to the property itself and the repayment obligation would therefore transfer with property ownership. The largest market to date, the U.S, has channelled more than $1.3 billion of PACE investment in 2020.

Conclusion

In conclusion, while the commitment of all stakeholders is commendable, it is evident that achieving a net-zero transition in the buildings sector requires a multifaceted approach. No single financial instrument can comprehensively address the diverse needs of this transition, encompassing various building types, technical aspects, and stakeholders. Instead, realizing net zero carbon status necessitates the coordination of a network of financial instruments tailored to these diverse requirements. Additionally, it requires a collective effort from both public and commercial lenders to offer incentives and products that genuinely motivate customers to embrace the Green Transition. By fostering collaboration and innovation across financial sectors, we can pave the way for a more sustainable built environment and a successful transition to net zero emissions.

Author Bios

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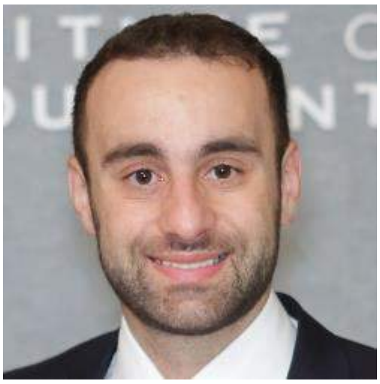
Professor Ruben Paul Borg is a Structural & Materials Engineer and academic at the University of Malta. He graduated in Civil Engineering and Architecture Hons. at the University of Malta and completed doctoral studies at the Politecnico di Milano and at the University of Sheffield. At the University of Malta he leads teaching and research in materials engineering and Sustainable Construction since 2002, is the Coordinator of the Industrial Heritage Platform and member of the Sustainability Committee at the University of Malta. He is Visiting Professor in Materials and Civil Engineering in International Academic Institutions.

Prof. Borg is Chartered Engineer, member Institution of Civil Engineers (UK) and its Malta Representative and Fellow of the Institution of Concrete Technology. He is member of the Board of Directors of iiSBE (International Initiative Sustainable Built Environment) and founded SBE Malta (Sustainable Built Environment Malta) as National Chapter. He was appointed Chairman of ECCE (European Council of Civil Engineers) for Knowledge and Technology; is active in RILEM (International Union of Laboratories and Experts in Construction Materials, Systems and Structures) scientific committees and fib (International Federation for Structural Concrete) as member of Commission 7: Sustainable Concrete and the Convenor of Task Group 7.8: High-Performance Concrete.

Prof. Borg was appointed Expert on the European Committee for Standardization CEN TC350 Sustainability of Construction Works and Malta's representative on the Construction Products Regulations Aquis. He was appointed on the Executive Committee of BICC Building Industry Consultative Council, Government of Malta and Chair of the Research and Innovation Committee. Prof. Borg is on the Editorial Board of high-impact International scientific Journals in Materials and Structures. He has led various EU Research Projects including Horizon 2020, Horizon Europe, Interreg

Med and Interreg Euro Med in High Performance Materials, Sustainable Construction, Structural Restoration and Built Environment Climate Adaptation.

He has led the execution of various project in civil engineering and conservation. Prof. Borg was awarded the International Energy Globe Award for the Sustainable Rehabilitation of the Xrobb l-Ghagin Sustainable Development Centre in 2013, and the Prix d'Honneur in Conservation, the Judge Caruana Curran Prize and the International Energy Globe Award for the Water Tower Conservation project in 2022.



Dr Ing. Damien Gatt
B.Eng (Hons) (Melit.), MSc (Sust. Energy) (Melit.), PhD (Melit.)
Sustainability, Zero Energy Buildings and data analysis expert

Dr Ing. Damien Gatt is a warranted mechanical engineer and holds an MSC and PhD in the field of Sustainable Energy from the University of Malta. He specialises in the modelling, design, and optimisation of Nearly Zero Energy Buildings (NZEB) with more than ten years of experience in the field. He has also lectured and published extensively in the field of sustainable buildings and has been cited more than 180 times. Damien has undertaken various energy retrofitting projects aimed at optimising both the energy performance and the improvement in thermal comfort and indoor air quality.

Damien is an ISO 5002 certified energy auditor and has performed energy audits of large enterprises, including five-star hotels and manufacturing industries. The sustainability projects that Damien has been involved in as project leader include the energy renovation of multiple large commercial and public buildings including schools and offices. Damien is also a technical policy expert and was one of the main consultants engaged to carry out the 2018 EPBD cost-optimal studies for Malta to establish minimum energy performance requirements.

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Appendix A

Measure/ package/ variant of measures	Wall option	Roof option	Fenestration option	Space heating & cooling option	Renewable energy (PVs) - option	Annual Exported PV site energy (kWh/yr)	Annual Site energy requirements (energy imported) (kWh/yr)	Annual Net Site energy (kWh/yr) (imported - exported)	Annual Net Primary Energy (kWh/yr)	Annual Net Primary Energy (kWh/m²/ yr)	% EP improvement
1	Reference (as is)	Reference (as is)	Reference (as is)	Reference (as is)	Reference - No PVs	0	2055763.16	2055763.16	4111526.32	467.22	0.00
2	Reference (as is)	Reference (as is)	Upgrade 2 (Al_double)	Reference (as is)	Reference - No PVs	0	2046327.74	2046327.74	4092655.48	465.07	0.46
3	Reference (as is)	Reference (as is)	Upgrade 3 (PVC_double)	Reference (as is)	Reference - No PVs	0	2046136.19	2046136.19	4092272.38	465.03	0.47
4	Reference (as is)	Reference (as is)	Upgrade 1 (Al_single_film)	Reference (as is)	Reference - No PVs	0	2026023.83	2026023.83	4052047.66	460.46	1.45
5	Reference (as is)	Reference (as is)	Upgrade 4 (Al_double_film)	Reference (as is)	Reference - No PVs	0	2019573.29	2019573.29	4039146.58	458.99	1.76
6	Reference (as is)	Reference (as is)	Upgrade 5 (PVC_double_film)	Reference (as is)	Reference - No PVs	0	2019403.33	2019403.33	4038806.66	458.96	1.77
7	Reference (as is)	Upgrade 1	Reference (as is)	Reference (as is)	Reference - No PVs	0	2006491.77	2006491.77	4012983.54	456.02	2.40
8	Reference (as is)	Upgrade 1	Upgrade 2 (Al_double)	Reference (as is)	Reference - No PVs	0	1995952.05	1995952.05	3991904.1	453.63	2.91
9	Reference (as is)	Upgrade 1	Upgrade 3 (PVC_double)	Reference (as is)	Reference - No PVs	0	1995773.53	1995773.53	3991547.06	453.58	2.92

10	Reference (as is)	Upgrade 1	Upgrade 1 (Al_single_film)	Reference (as is)	Reference - No PVs	0	1972648.39	1972648.39	3945296.78	448.33	4.04
11	Reference (as is)	Upgrade 1	Upgrade 4 (Al_double_film)	Reference (as is)	Reference - No PVs	0	1966077.63	1966077.63	3932155.26	446.84	4.36
12	Reference (as is)	Upgrade 1	Upgrade 5 (PVC_double_film)	Reference (as is)	Reference - No PVs	0	1965869.2	1965869.2	3931738.4	446.79	4.37
13	Upgrade 1	Reference (as is)	Reference (as is)	Reference (as is)	Reference - No PVs	0	2040004.47	2040004.47	4080008.94	463.64	0.77
14	Upgrade 1	Reference (as is)	Upgrade 2 (Al_double)	Reference (as is)	Reference - No PVs	0	2029698.86	2029698.86	4059397.72	461.30	1.27
15	Upgrade 1	Reference (as is)	Upgrade 3 (PVC_double)	Reference (as is)	Reference - No PVs	0	2029541.73	2029541.73	4059083.46	461.26	1.28
16	Upgrade 1	Reference (as is)	Upgrade 1 (Al_single_film)	Reference (as is)	Reference - No PVs	0	2005545.98	2005545.98	4011091.96	455.81	2.44
17	Upgrade 1	Reference (as is)	Upgrade 4 (Al_double_film)	Reference (as is)	Reference - No PVs	0	1999424.95	1999424.95	3998849.9	454.41	2.74
18	Upgrade 1	Reference (as is)	Upgrade 5 (PVC_double_film)	Reference (as is)	Reference - No PVs	0	1999293.42	1999293.42	3998586.84	454.38	2.75
19	Upgrade 1	Upgrade 1	Reference (as is)	Reference (as is)	Reference - No PVs	0	1988538.07	1988538.07	3977076.14	451.94	3.27
20	Upgrade 1	Upgrade 1	Upgrade 2 (Al_double)	Reference (as is)	Reference - No PVs	0	1976380.18	1976380.18	3952760.36	449.18	3.86
21	Upgrade 1	Upgrade 1	Upgrade 3 (PVC_double)	Reference (as is)	Reference - No PVs	0	1976201.74	1976201.74	3952403.48	449.14	3.87
22	Upgrade 1	Upgrade 1	Upgrade 1 (Al_single_film)	Reference (as is)	Reference - No PVs	0	1949824.2	1949824.2	3899648.4	443.14	5.15

23	Upgrade 1	Upgrade 1	Upgrade 4 (Al_double_film)	Reference (as is)	Reference - No PVs	0	1942661.22	1942661.22	3885322.44	441.51	5.50
24	Upgrade 1	Upgrade 1	Upgrade 5 (PVC_double_film)	Reference (as is)	Reference - No PVs	0	1942337.38	1942337.38	3884674.76	441.44	5.52
25	Reference (as is)	Reference (as is)	Reference (as is)	New_VRF	Reference - No PVs	0	1581430.15	1581430.15	3162860.3	359.42	23.07
26	Reference (as is)	Reference (as is)	Upgrade 2 (Al_double)	New_VRF	Reference - No PVs	0	1576149.25	1576149.25	3152298.5	358.22	23.33
27	Reference (as is)	Reference (as is)	Upgrade 3 (PVC_double)	New_VRF	Reference - No PVs	0	1576048	1576048	3152096	358.19	23.34
28	Reference (as is)	Reference (as is)	Upgrade 1 (Al_single_film)	New_VRF	Reference - No PVs	0	1565196.9	1565196.9	3130393.8	355.73	23.86
29	Reference (as is)	Reference (as is)	Upgrade 4 (Al_double_film)	New_VRF	Reference - No PVs	0	1561603.83	1561603.83	3123207.66	354.91	24.04
30	Reference (as is)	Reference (as is)	Upgrade 5 (PVC_double_film)	New_VRF	Reference - No PVs	0	1561514.72	1561514.72	3123029.44	354.89	24.04
31	Reference (as is)	Upgrade 1	Reference (as is)	New_VRF	Reference - No PVs	0	1550094.21	1550094.21	3100188.42	352.29	24.60
32	Reference (as is)	Upgrade 1	Upgrade 2 (Al_double)	New_VRF	Reference - No PVs	0	1544187.35	1544187.35	3088374.7	350.95	24.88
33	Reference (as is)	Upgrade 1	Upgrade 3 (PVC_double)	New_VRF	Reference - No PVs	0	1544087.53	1544087.53	3088175.06	350.93	24.89
34	Reference (as is)	Upgrade 1	Upgrade 1 (Al_single_film)	New_VRF	Reference - No PVs	0	1531687.3	1531687.3	3063374.6	348.11	25.49
35	Reference (as is)	Upgrade 1	Upgrade 4 (Al_double_film)	New_VRF	Reference - No PVs	0	1527961.09	1527961.09	3055922.18	347.26	25.67

36	Reference (as is)	Upgrade 1	Upgrade 5 (PVC_double_film)	New_VRF	Reference - No PVs	0	1527847.65	1527847.65	3055695.3	347.24	25.68
37	Upgrade 1	Reference (as is)	Reference (as is)	New_VRF	Reference - No PVs	0	1570872.2	1570872.2	3141744.4	357.02	23.59
38	Upgrade 1	Reference (as is)	Upgrade 2 (Al_double)	New_VRF	Reference - No PVs	0	1565169.37	1565169.37	3130338.74	355.72	23.86
39	Upgrade 1	Reference (as is)	Upgrade 3 (PVC_double)	New_VRF	Reference - No PVs	0	1565083.22	1565083.22	3130166.44	355.70	23.87
40	Upgrade 1	Reference (as is)	Upgrade 1 (Al_single_film)	New_VRF	Reference - No PVs	0	1552117.06	1552117.06	3104234.12	352.75	24.50
41	Upgrade 1	Reference (as is)	Upgrade 4 (Al_double_film)	New_VRF	Reference - No PVs	0	1548751.71	1548751.71	3097503.42	351.99	24.66
42	Upgrade 1	Reference (as is)	Upgrade 5 (PVC_double_film)	New_VRF	Reference - No PVs	0	1548682.21	1548682.21	3097364.42	351.97	24.67
43	Upgrade 1	Upgrade 1	Reference (as is)	New_VRF	Reference - No PVs	0	1538104.75	1538104.75	3076209.5	349.57	25.18
44	Upgrade 1	Upgrade 1	Upgrade 2 (Al_double)	New_VRF	Reference - No PVs	0	1531384.98	1531384.98	3062769.96	348.04	25.51
45	Upgrade 1	Upgrade 1	Upgrade 3 (PVC_double)	New_VRF	Reference - No PVs	0	1531286.97	1531286.97	3062573.94	348.02	25.51
46	Upgrade 1	Upgrade 1	Upgrade 1 (Al_single_film)	New_VRF	Reference - No PVs	0	1517100.69	1517100.69	3034201.38	344.80	26.20
47	Upgrade 1	Upgrade 1	Upgrade 4 (Al_double_film)	New_VRF	Reference - No PVs	0	1513075.98	1513075.98	3026151.96	343.88	26.40
48	Upgrade 1	Upgrade 1	Upgrade 5 (PVC_double_film))	New_VRF	Reference - No PVs	0	1512874.92	1512874.92	3025749.84	343.84	26.41

49	Reference (as is)	Reference (as is)	Reference (as is)	Reference (as is)	PVs (52 kWp)	84000	2055763.16	1971763.16	3943526.32	448.13	4.09
50	Reference (as is)	Reference (as is)	Upgrade 2 (Al_double)	Reference (as is)	PVs (52 kWp)	84000	2046327.74	1962327.74	3924655.48	445.98	4.55
51	Reference (as is)	Reference (as is)	Upgrade 3 (PVC_double)	Reference (as is)	PVs (52 kWp)	84000	2046136.19	1962136.19	3924272.38	445.94	4.55
52	Reference (as is)	Reference (as is)	Upgrade 1 (Al_single_film)	Reference (as is)	PVs (52 kWp)	84000	2026023.83	1942023.83	3884047.66	441.37	5.53
53	Reference (as is)	Reference (as is)	Upgrade 4 (Al_double_film)	Reference (as is)	PVs (52 kWp)	84000	2019573.29	1935573.29	3871146.58	439.90	5.85
54	Reference (as is)	Reference (as is)	Upgrade 5 (PVC_double_film)	Reference (as is)	PVs (52 kWp)	84000	2019403.33	1935403.33	3870806.66	439.86	5.85
55	Reference (as is)	Upgrade 1	Reference (as is)	Reference (as is)	PVs (52 kWp)	84000	2006491.77	1922491.77	3844983.54	436.93	6.48
56	Reference (as is)	Upgrade 1	Upgrade 2 (Al_double)	Reference (as is)	PVs (52 kWp)	84000	1995952.05	1911952.05	3823904.1	434.53	7.00
57	Reference (as is)	Upgrade 1	Upgrade 3 (PVC_double)	Reference (as is)	PVs (52 kWp)	84000	1995773.53	1911773.53	3823547.06	434.49	7.00
58	Reference (as is)	Upgrade 1	Upgrade 1 (Al_single_film)	Reference (as is)	PVs (52 kWp)	84000	1972648.39	1888648.39	3777296.78	429.24	8.13
59	Reference (as is)	Upgrade 1	Upgrade 4 (Al_double_film)	Reference (as is)	PVs (52 kWp)	84000	1966077.63	1882077.63	3764155.26	427.74	8.45
60	Reference (as is)	Upgrade 1	Upgrade 5 (PVC_double_film)	Reference (as is)	PVs (52 kWp)	84000	1965869.2	1881869.2	3763738.4	427.70	8.46
61	Upgrade 1	Reference (as is)	Reference (as is)	Reference (as is)	PVs (52 kWp)	84000	2040004.47	1956004.47	3912008.94	444.55	4.85

62	Upgrade 1	Reference (as is)	Upgrade 2 (Al_double)	Reference (as is)	PVs (52 kWp)	84000	2029698.86	1945698.86	3891397.72	442.20	5.35
63	Upgrade 1	Reference (as is)	Upgrade 3 (PVC_double)	Reference (as is)	PVs (52 kWp)	84000	2029541.73	1945541.73	3891083.46	442.17	5.36
64	Upgrade 1	Reference (as is)	Upgrade 1 (Al_single_film)	Reference (as is)	PVs (52 kWp)	84000	2005545.98	1921545.98	3843091.96	436.71	6.53
65	Upgrade 1	Reference (as is)	Upgrade 4 (Al_double_film)	Reference (as is)	PVs (52 kWp)	84000	1999424.95	1915424.95	3830849.9	435.32	6.83
66	Upgrade 1	Reference (as is)	Upgrade 5 (PVC_double_film)	Reference (as is)	PVs (52 kWp)	84000	1999293.42	1915293.42	3830586.84	435.29	6.83
67	Upgrade 1	Upgrade 1	Reference (as is)	Reference (as is)	PVs (52 kWp)	84000	1988538.07	1904538.07	3809076.14	432.85	7.36
68	Upgrade 1	Upgrade 1	Upgrade 2 (Al_double)	Reference (as is)	PVs (52 kWp)	84000	1976380.18	1892380.18	3784760.36	430.09	7.95
69	Upgrade 1	Upgrade 1	Upgrade 3 (PVC_double)	Reference (as is)	PVs (52 kWp)	84000	1976201.74	1892201.74	3784403.48	430.05	7.96
70	Upgrade 1	Upgrade 1	Upgrade 1 (Al_single_film)	Reference (as is)	PVs (52 kWp)	84000	1949824.2	1865824.2	3731648.4	424.05	9.24
71	Upgrade 1	Upgrade 1	Upgrade 4 (Al_double_film)	Reference (as is)	PVs (52 kWp)	84000	1942661.22	1858661.22	3717322.44	422.42	9.59
72	Upgrade 1	Upgrade 1	Upgrade5 (PVC_double_film)	Reference (as is)	PVs (52 kWp)	84000	1942337.38	1858337.38	3716674.76	422.35	9.60
73	Reference (as is)	Reference (as is)	Reference (as is)	New_VRF	PVs (52 kWp)	84000	1581430.15	1497430.15	2994860.3	340.33	27.16
74	Reference (as is)	Reference (as is)	Upgrade 2 (Al_double)	New_VRF	PVs (52 kWp)	84000	1576149.25	1492149.25	2984298.5	339.12	27.42
75	Reference (as is)	Reference (as is)	Upgrade 3 (PVC_double)	New_VRF	PVs (52 kWp)	84000	1576048	1492048	2984096	339.10	27.42
76	Reference (as is)	Reference (as is)	Upgrade 1 (Al_single_film)	New_VRF	PVs (52 kWp)	84000	1565196.9	1481196.9	2962393.8	336.64	27.95
77	Reference (as is)	Reference (as is)	Upgrade 4 (Al_double_film)	New_VRF	PVs (52 kWp)	84000	1561603.83	1477603.83	2955207.66	335.82	28.12

78	Reference (as is)	Reference (as is)	Upgrade 5 (PVC_double_film)	New_VRF	PVs (52 kWp)	84000	1561514.72	1477514.72	2955029.44	335.80	28.13
79	Reference (as is)	Upgrade 1	Reference (as is)	New_VRF	PVs (52 kWp)	84000	1550094.21	1466094.21	2932188.42	333.20	28.68
80	Reference (as is)	Upgrade 1	Upgrade 2 (Al_double)	New_VRF	PVs (52 kWp)	84000	1544187.35	1460187.35	2920374.7	331.86	28.97
81	Reference (as is)	Upgrade 1	Upgrade 3 (PVC_double)	New_VRF	PVs (52 kWp)	84000	1544087.53	1460087.53	2920175.06	331.84	28.98
82	Reference (as is)	Upgrade 1	Upgrade 1 (Al_single_film)	New_VRF	PVs (52 kWp)	84000	1531687.3	1447687.3	2895374.6	329.02	29.58
83	Reference (as is)	Upgrade 1	Upgrade 4 (Al_double_film)	New_VRF	PVs (52 kWp)	84000	1527961.09	1443961.09	2887922.18	328.17	29.76
84	Reference (as is)	Upgrade 1	Upgrade5 (PVC_double_film)	New_VRF	PVs (52 kWp)	84000	1527847.65	1443847.65	2887695.3	328.15	29.77
85	Upgrade 1	Reference (as is)	Reference (as is)	New_VRF	PVs (52 kWp)	84000	1570872.2	1486872.2	2973744.4	337.93	27.67
86	Upgrade 1	Reference (as is)	Upgrade 2 (Al_double)	New_VRF	PVs (52 kWp)	84000	1565169.37	1481169.37	2962338.74	336.63	27.95
87	Upgrade 1	Reference (as is)	Upgrade 3 (PVC_double)	New_VRF	PVs (52 kWp)	84000	1565083.22	1481083.22	2962166.44	336.61	27.95
88	Upgrade 1	Reference (as is)	Upgrade 1 (Al_single_film)	New_VRF	PVs (52 kWp)	84000	1552117.06	1468117.06	2936234.12	333.66	28.59
89	Upgrade 1	Reference (as is)	Upgrade 4 (Al_double_film)	New_VRF	PVs (52 kWp)	84000	1548751.71	1464751.71	2929503.42	332.90	28.75
90	Upgrade 1	Reference (as is)	Upgrade5 (PVC_double_film)	New_VRF	PVs (52 kWp)	84000	1548682.21	1464682.21	2929364.42	332.88	28.75
91	Upgrade 1	Upgrade 1	Reference (as is)	New_VRF	PVs (52 kWp)	84000	1538104.75	1454104.75	2908209.5	330.48	29.27

92	Upgrade 1	Upgrade 1	Upgrade 2 (Al_double)	New_VRF	PVs (52 kWp)	84000	1531384.98	1447384.98	2894769.96	328.95	29.59
93	Upgrade 1	Upgrade 1	Upgrade 3 (PVC_double)	New_VRF	PVs (52 kWp)	84000	1531286.97	1447286.97	2894573.94	328.93	29.60
94	Upgrade 1	Upgrade 1	Upgrade 1 (Al_single_film)	New_VRF	PVs (52 kWp)	84000	1517100.69	1433100.69	2866201.38	325.70	30.29
95	Upgrade 1	Upgrade 1	Upgrade 4 (Al_double_film)	New_VRF	PVs (52 kWp)	84000	1513075.98	1429075.98	2858151.96	324.79	30.48
96	Upgrade 1	Upgrade 1	Upgrade5 (PVC_double_film)	New_VRF	PVs (52 kWp)	84000	1512874.92	1428874.92	2857749.84	324.74	30.49

Appendix B

Costs considered for different external wall construction

Wall measure Options	Specific measure property (Wall U-Value (W/m²K))	Assumed in costs	Labour cost (€/m²of wall area)	Cost of technology (€/m²of wall area)	Total Initial investment cost (€/m²of wall area)	Annual Maintenance cost as % of investment cost	Annual maintenance cost (€/m²of wall area)	Residual Value (€/m² of wall area)	Typical re-investment costs (€/m² of envelope area)	Year in which re-investment is made	Assumed lifetime (Years)
Reference	2.1	Reference - not applicable	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.00
Upgrade 1	0.5	Application of 5 cm XPS	40.00	17.30	57.30	0.00	0.00	19.10	0.00	0.00	30.00

Costs considered for different roof construction

Roof measure Options	Specific measure property (Wall U-Value (W/m²K))	Assumed in costs	Labour cost (€/m²of wall area)	Cost of technology (€/m²of wall area)	Total Initial investment cost (€/m²of wall area)	Annual Maintenance cost as % of investment cost	Annual maintenance cost (€/m²of wall area)	Residual Value (€/m² of wall area)	Typical re-investment costs (€/m² of envelope area)	Year in which re-investment is made	Assumed lifetime (Years)
Reference	1.7	Reference - not applicable	0.00	0	0.00	0	0.00	0.00	0	0	30
Upgrade 1	0.4	Application of 5/6 cm XPS	25	27	52	0	0.00	17.33	0	0	30

Considered for different window (glazing + frame) constructions of existing offices

Fenestration measure Options	**Assumed in costs**	**Labour cost (€/m²of window area)**	**Cost of technology (€/m²of window area)**	**Total Initial investment cost (€/m²of window area)**	**Annual Maintenance cost as % of investment cost**	**Annual maintenance cost (€/m²of window area)**	**Residual Value ((€/m² of window area)**	**Typical re-investment costs (€/m² of window area)**	**Year in which re-investment is made**	**Assumed lifetime (Years)**
Reference (as is)	None	0	0	0	0	0	0	0	0	30
Upgrade 1	Application of spectrally selective film retaining current glazing	20	66	86	0	0	0	0	0	Film will be replaced after 10 years at no learning rate
Upgrade 2	Replace Single clear glazing with double pane clear glazing with Aluminium frame	130	88	218	0	0	72.76	0	0	30

Fenestration measure Options	Assumed in costs	Labour cost (€/m²of window area)	Cost of technology (€/m²of window area)	Total Initial investment cost (€/m²of window area)	Annual Maintenance cost as % of investment cost	Annual maintenance cost (€/m²of window area)	Residual Value ((€/m² of window area)	Typical re-investment costs (€/m² of window area)	Year in which re-investment is made	Assumed lifetime (Years)
Upgrade 3	Replace Single clear glazing with double pane clear glazing with spectrally selective film (PR70) and Aluminium frame	140	115	255	0	0	85	0	0	30
Upgrade 4	Replace Single clear glazing with double pane clear glazing with PVC/thermal break frame	150	88	238	0	0	79.33	0	0	30

Fenestration measure Options	**Assumed in costs**	**Labour cost (€/m²of window area)**	**Cost of technology (€/m²of window area)**	**Total Initial investment cost (€/m²of window area)**	**Annual Maintenance cost as % of investment cost**	**Annual maintenance cost (€/m²of window area)**	**Residual Value ((€/m² of window area)**	**Typical re-investment costs (€/m² of window area)**	**Year in which re-investment is made**	**Assumed lifetime (Years)**
Upgrade 5	Replace Single clear glazing with double pane clear glazing with spectrally selective film (PR70) and PVC/thermal break frame	165	115	280	0	0	93.33	0	0	30

Costs considered for different space heating and cooling equipment options

Space heating/cooling measure Options	Assumed in costs	Labour cost (€)	Cost of technology (€)	Total Initial investment cost (€)	Annual Maintenance cost as % of investment cost	Annual maintenance cost (€)	Residual Value (€)	Typical re-investment costs (€)	Year in which re-investment is made	Assumed lifetime (Years)
Reference (as is)	None					15600	260000	New system will be in place after 15 years at capital cost Euro 390000		15
Upgrade 1	Replace VRF system (without ventilation system) – circa 600 kW	130000	260000	390000	2	7800	260000	0		15 (System will be replaced after 15 years @ no learning rate)

Costs considered for different Renewable energy system options

Space heating/cooling measure Options	Assumed in costs	Labour cost (€)	Cost of technology (€)	Total Initial investment cost (€)	Annual Maintenance cost as % of investment cost	Annual maintenance cost (€)	Residual Value (€)	Typical re-investment costs (€)	Year in which re-investment is made	Assumed lifetime (Years)
Reference (as is)	None (No PVs)									
Upgrade 1	Installation of 52 kWp Photovoltaic panels			67600	1	676	11266	3403 (Inverters replacement)	10	24