STATISTICAL ANALYSIS OF ENERGY PERFORMANCE CERTIFICATES OF MALTESE OFFICES

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DECLARATION

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

Signature of Student

Name of Student

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June 2022

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ABSTRACT

The number of energy performance certificates (EPCs) of offices in Malta represent around 18.60% of the total stock of EPCs for non-dwellings between the period 2010 and 2018, which is significant. Consequently, this dissertation aims to analyse these certificates in order to determine the overall statistical distribution and to identify the worst performing categories, in accordance with the updated EU Energy Performance of Buildings Directive (EU) 2018/844, and to propose pathways to improve their performance through deep renovation to near zero-energy status.

Office buildings were categorised into four different groups based on total floor area which is in line with the National Cost Optimal Study of 2018 (≤ 250, ≤ 500, ≤ 1500 and >1500 m^2). Results have shown that the primary energy rating and its corresponding Energy Class Rating of these office clusters are different in value, which justifies the categorisation by floor area. Statistical analysis has also revealed that most offices had Energy Class C or D, with the larger offices exhibiting more efficient tendencies (Classes B and C). A number of offices have been considered as outliers because they had EPC rating that were beyond the acceptable limits of statistical tests such as Box and Whiskers Plot, Residual Plots, One-Way ANOVA and Regression Analyses.

The study on energy efficiency measures was divided into three main parts, namely the building envelope, the building energy systems and renewables (solar photovoltaics). It was found that the implementation of the optimum building envelope and building energy system measures have yielded an improvement ranging from 28% to 46% for the four office clusters, which is significant and in line with the EU “Energy Efficiency First” Principle, whereby one needs to reduce energy demand before applying renewable energy. With the addition of solar photovoltaics at roof level, all office clusters demonstrated a high potential of achieving a positive renewable energy building, which means that the office becomes a net energy producer.

In conclusion, it was recommended that stronger control is needed to ensure quality EPCs. Results that are far from reasonable should clearly be justified or reviewed. Moreover, this study has identified the potential available for the office building sector to contribute towards its decarbonisation with clear and well defined stepped approach, which should help the policy maker to take informed decisions on the deep renovation approaches to be considered for office buildings.

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Finally, I acknowledge the support of the Building and Construction Authority for providing access to the statistical data without which this project could not have been carried out.

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LIST OF ABREVIATIONS

A

AC	Air Conditioner
ACOMV	Ant Colony Optimisation Algorithm form Mixed Variables
ACOMV-M	Modified Ant Colony Optimisation Algorithm for Mixed Variables
AIEPtot	Total Average of the Energy Performance index
ANOVA	ANalysis Of VAriance

B

BEECs	Building Energy Efficiency Certificates
BOP	Building Optimisation Problems

C

CEEA	Clean Energy for All Europeans
CME	Coordinated Market Economy
COP	Coefficient Of Performance
COP 26	Conference of Parties

D

DHS	District Heating System
DME	Dependent Market Economy

E

EED	Energy Efficiency Directive
EPBD	Energy Performance of Building Directive
EPCs	Energy Performance Certificate
EPRDM	Energy Performance of Residential Dwellings
EPtot	Total Energy Performance index
EU	European Union
EUI	Energy Use Index

I

IGB	Individual Gas Boiler

K

KNDB	Korean National Database

L	
LME	Liberal Market Economy
LTRS	Long Term Renovation Strategy
M	
MOLIT	Ministry of Land, Transport and Infrastructure
Mtoe	Million Tonnes of Oil Equivalent
N	
ND	Non-Data
P	
POP	Persistent Organic Pollutant
PSOHJ	Particle Swarm and Hook Jeeves Hybrid Optimisation
PV	Photovoltaic system
S	
SACE	Sistema Accreditamento Cerificatori Energetici,
SBEM	Simplified Building Energy Model
SBEM-mt	Simplified Building Energy Model for Malta
SC	Silhouette Coefficient
T	
TBC	Technical Building Code
U	
UNCC	United Nations Climate Conference

CHAPTER 1: INTRODUCTION

If one takes a look at the current situation of the renewable energy sector, one can easily glimpse that the trend of European and non-European governments is to rely as little as possible on fossil fuels and support a more sustainable world.

In order to reach the 2050 targets of zero carbon emissions, which were set during the Paris Agreement [1], it is necessary for the European Union to focus on evaluating all possible alternatives to develop energy systems that are efficient and do not cost more than the systems to be replaced.

In addition, the growing concern for the environment in today's 21st century society creates a strong incentive for governments in order to act in favour of the development and research of these alternative energy sources [3] [6].

One of the main solutions proposed by scientists is the intensification of wind farm constructions, while others advocate promoting the importance of solar photovoltaics in everyday life, which already accounts for “11,6%” of the share of electricity generation in Europe [1].

Furthermore, it is estimated that the EU Green Transition will have a great impact on society and economy of all Europeans, creating around 1.5 million jobs over the next three decades [1] [2].

In other words, one can be sure that there is no turning back and no alternative to the global energy transition led by countries such as Denmark, Norway or Sweden.

For these reasons and with the aim of achieving the transition as soon as possible, governments and companies are working together on research and balanced development of the sector independently of the different economies belonging to the European Union, such as the German coordinated market economy (CME), outside the European Union, such as the English liberal market economy (LME) or the dependent market economy (DME) that arises mainly in the states belonging to Central/Eastern Europe [4].

Overall, the energy consumption of public and private buildings in the EU amounts to 40% of the total, also accounting for 35% of greenhouse gas and persistent organic pollutant (POP) emissions. For these very reasons, achieving energy efficiency in public and private buildings is fundamental to reaching the carbon neutrality set out in the European Green Pact by 2050 [5]. It is to be noted that in the context of the EU Energy Performance of Buildings Directive (EPBD) (EU) 2018/844 [8], industrial buildings are not included, because most of the energy consumption in factories is attributed to machinery. For that purpose, other directives apply for their efficiency.

Various ways of achieving the expected level of energy efficiency can be found today. One of them, perhaps the simplest, is based on the construction of new buildings that are already efficient. However, the most pressing and also the most economical is based on identifying which existing buildings are efficient and which are not, with the intention of classifying them and subsequently seeking measures to improve their efficiency as far as possible, especially for the worst performing categories [7].

1.1 NEED OF THE DISSERTATION

Before delving into the need for this study, it is important to first appreciate that the EU supports studies and researches on energy efficiency in buildings through Directive (EU) 2018/844 [8], which aims to be a guide on energy performance in buildings in the Union, and complementing the previous Directive 2010/31/EU of the European Parliament and Council [9]. This directive also links with the Renewable Energy directive (EU) 2001/2018 [9] and the Energy Efficiency directive (EU) 2002/2018 [9], which has replaced the 2012/27/EU [10]. Together, these directives are pushing the EU, a step forward to achieve carbon neutrality by 2050.

This drive towards decarbonisation is also reflected in the form of new policy developments such as the latest Clean Energy for All Europeans (CEEA) packages or the COP 26 of the United Nations Climate Conference (UNCC), which was held in Glasgow in 2021 [2].

Figures 1 and 2 show how energy consumption by the service sector in Europe took up to 13.7% of the total European share [11], being the third most important sector next to the industrial and residential sectors. The graphical data is shown in million tonnes of oil equivalent (Mtoe).

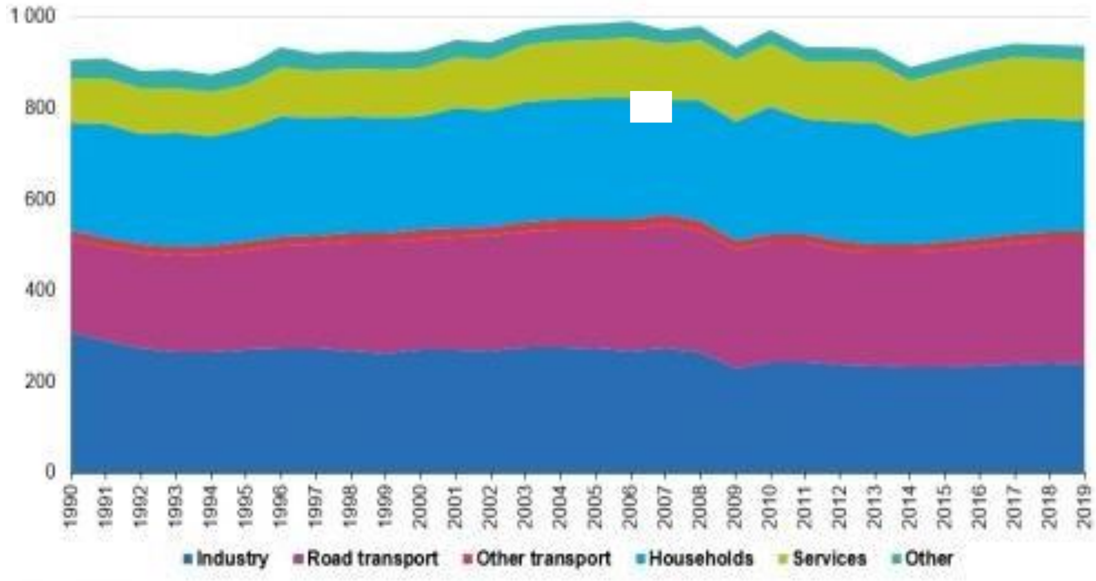


Figure 1. Share of energy consumption for the main consuming sectors in the EU in 2019 (Mtoe) [11].

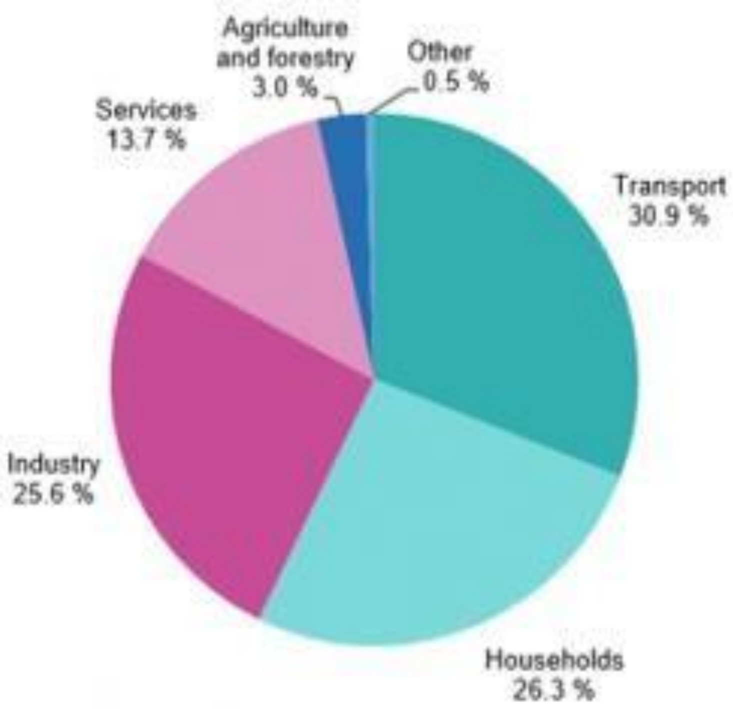


Figure 2. Final energy consumption by EU energetic sectors from 1990 to 2019 [11].

In this work, buildings belonging specifically to the category of offices making part of the service sector will be studied. One of the approaches that is recommended by the EPBD is to statistically analyse the energy performance certificates (EPCs) of existing buildings to determine the extent to which they are efficient and to identify the worst performing levels. The EPC became mandatory for buildings that are already sold or rented out and for which the Planning Authority requires a building permit for any new construction or a change of use as of 1 June 2009 [12].

Also, one of the instruments of the new EPBD (EU) 2018/844 is for EU Member States to prepare a long-term renovation strategy for existing buildings (LTRS) for the period up to 2030. Malta’s draft LTRS is completely focused on dwellings and has not carried out sufficent analysis on non-residential buildings [14].

Therefore, this research will focus on offices being one of the most popular buildings in Malta, given that Malta’s economy is based on the services rather than on the manufacturing sector, which implies that most of the economic activities occur in offices. Once the energy performance analysis status quo is identified, one can carry out studies to determine the optimum energy efficiency measures that can sustainably improve their performance. The chosen measures should ideally add value and improve the energy efficiency of these buildings and of future buildings of the same characteristics on the long term. This justified the need for this dissertation early in this decade between 2021 and 2030.

1.2 STATISTICAL ANALYSIS OF EPCS

An Energy Performance Certificate (EPC) is an official label similar to the labels on household appliances, which incorporate different scales that are differentiated by the amount of carbon emissions emanating from the building and its energy rating.

In addition, the EPC includes advice and recommendations so that the owner is aware of how to improve the condition of their property [18]. As presented in Figure 3, there are different grades ranging from "G" to "A", with the first letter named being the least energy efficient and the last letter named the most energy efficient. In addition, there is an extra rating called "A+" for those properties that are not only energy efficient (A), but also produce more renewable energy than they consume (+).

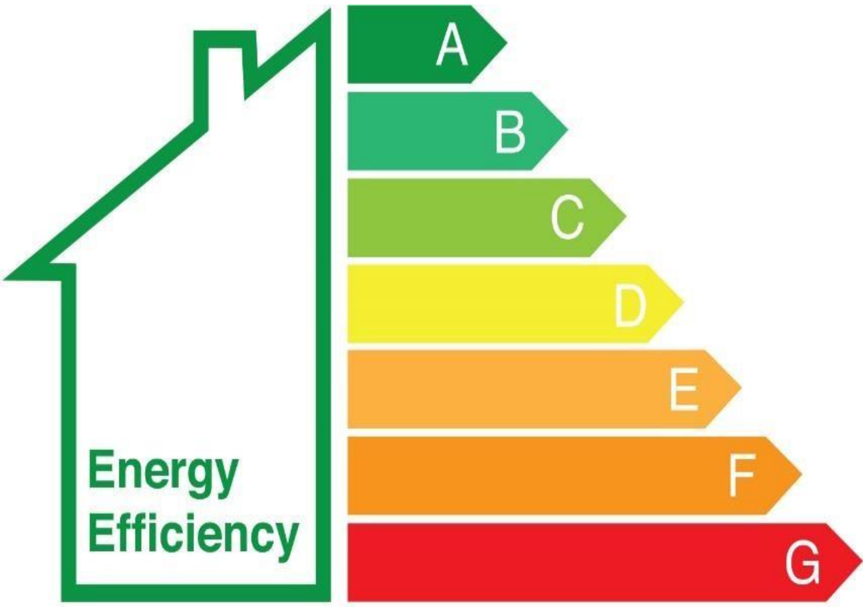


Figure 3. Energy Performance Certificate or EPC.

It is important to clarify that the energy rating provided in the EPC depends on the total floor area of the building as it is measured in units of primary energy (total energy extracted from the fuel source) and expressed as **kWh/ m^2*year.** Furthermore, primary energy is differentiated from energy used or end-use energy in that the first is the total energy found in fuel by nature and the second is the energy actually consumed by the end user. The ratio between them provides the overall efficiency or inefficiency of the global energy conversion process [7].

Since 1 June 2009 all new, for sale or rented buildings as well as all public buildings must show their EPC or its copy in order to pass the inspection and be accepted. This EU requirement was transposed to Maltese legislation as shown in Regulation L.N. 47 of 2018 [15], contained in Directive 2010/31/EU [9]. This inspection shall include assessments of the energy efficiency for main energy-consuming systems of the building.

In Malta EPCs are generated by software, Energy Performance of Residential Dwellings Malta (EPRDM) for dwellings [19] and Simplified Building Energy Model (SBEM) for Energy Performance Certifications for Non-Dwellings [20].

As several authors concluded, the Energy Efficiency Certificates, whether old or renewed, can be used to study the growth of energy efficiency as well as help in the assessment of the effect on energy efficiency of the policy-making and procedures carried out by public administrations [18]. In fact, a number of cost optimal studies for different building categories have been carried out for Malta [16] and these include new office category. However, these studies were not done on the basis of statistical analysis of the total number of existing or new office buildings but on assumed reference building types. Therefore, the added value of this research will be to confirm or otherwise the conclusions attained in this study as well.

1.3 EU DIRECTIVES AND IMPLEMENTATION IN MALTA

1.4 DISSERTATION AIMS AND OBJECTIVES

1.4.1 DISSERTATION AIMS

The main objective of the thesis is to:

Establish the statistical distribution of energy performance rating of offices in Malta based on the official energy performance certificates and prioritise energy efficiency measures that can effectively improve the primary energy of the worst performing offices.

1.4.2 DISSERTATION OBJECTIVES

In order to achieve the main aim of this work, the following objectives have been defined:

1. Analyse the available EPCs of offices.

2. Statistically calculate reference values for the offices and determine typical benchmarks.

3. Apply energy efficiency measures to the worst performing category and determine a hierarchy of the most effective energy efficiency measures.

1.4.2.1 JUSTIFICATION OF DISSERTATION OBJECTIVES

When analysing data pertaining to energy rating of offices, it is important to first determine a typical office benchmark using statistical methods in order to be able to carry out additional studies on the energy efficiency of Maltese offices.

As mentioned in previous sections of this chapter, the EU Directive 2018/844 [8] establishes a reference framework for all EU member States and commits them to implement a sustainable and decarbonised energy strategy. In addition, the Framework for Climate and Energy Action to 2030 [21] sets out new targets, policies and key measures to renew the EU's energy mix, as well as to complete the reduction of environmentally harmful gases emissions by at least 45% compared to the decade of the 90s and sets out its commitment to increase the share of energy consumed from renewable energy, as well as to energy savings and the renewal of energy systems across the EU.

In addition, as shown in Figure 4 [22], Directive 2018/844 also includes the emission of new European Structural and Investment Funds [8] that aim to improve capacities for the development of energy efficient systems:

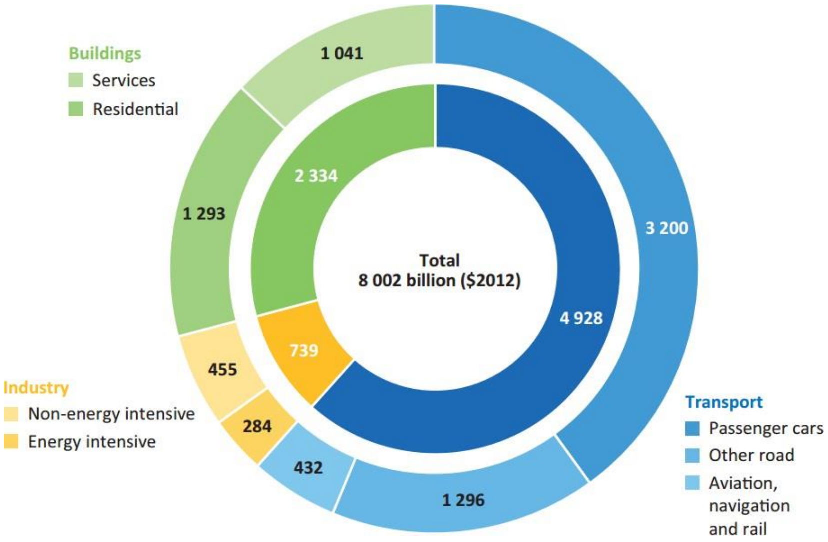


Figure 4. Cumulative global investment in energy efficiency analysed by sector of final consumption in the New Policies Scenario. [22].

Therefore, the need to meet the objectives set out in this dissertation is more than justified and supported by the new energy policies carried out in recent years by the governments of both European and non-EU countries, serving as a basis for further analysis, studies and projects on energy renovation.

In addition, Malta's Long Term Renovation Strategy (LTRS) did not delve deeply into the analysis of energy performance of non-residential buildings and therefore this research adds value to knowledge by providing significant advancement on the state of the technology with respect to the available information on the status quo of Maltese offices with respect to their energy performance rating.

1.5 STRUCTURE

The structure to be followed during the completion of the thesis is as follows:

Chapter 1: Introduction, definition of EPCs, aims and objectives of the dissertation, argumentation of the analysis and final structure of the dissertation.

Chapter 2: Literature review and its relevance to this thesis, EU Directives and their adoption and implementation.

Chapter 3: Methodology used in this dissertation.

Chapter 4: Results of the statistical analysis and evaluation of the results obtained, possible measures to be taken for the improvement of energy efficiency in offices.

Chapter 5: Conclusions and recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 CASE STUDIES AND FINDINGS

2.1.1 EU CASE STUDIES

In Trondheim, Norway, a large office building with digital monitoring and control systems was used as a case study [24]. Using the data collected by these systems, a statistical study was carried out to determine the electricity use in the whole building and its characteristics, analysing the consumption in corridors and the consumption in offices and rooms, as well as the electricity consumption based on the occupancy of the building by applying the polynomial regression method [23], as shown in Eq. 1.

$$y = a_0 + a_1 x + a_2 x^2 + \cdots + a_n x^n \qquad \text{(Eq. 1)}$$

Where $a_0, \ldots, a_n$ are the parameters of the equation to be found and n is the degree of the polynomial, y is the electricity consumption and x is the occupancy of the office. In our study of energy efficiency in offices we could also use linear regression e.g. to study the relationship between the energy ratings of the EPCs in the database and their floor area.

In Figure 5, the study building is shown. For the study, various devices (e.g. sensors, actuators) were installed to monitor both the environment and energy use and it was determined that 42.45% of all energy used was consumed directly by the offices, as shown in Figure 6. Also, it was found that as occupancy increases the consumption of electricity in the office areas also increases along a curve as shown in Figure 7 [24].

Figure 5. Building structure illustrated [24].

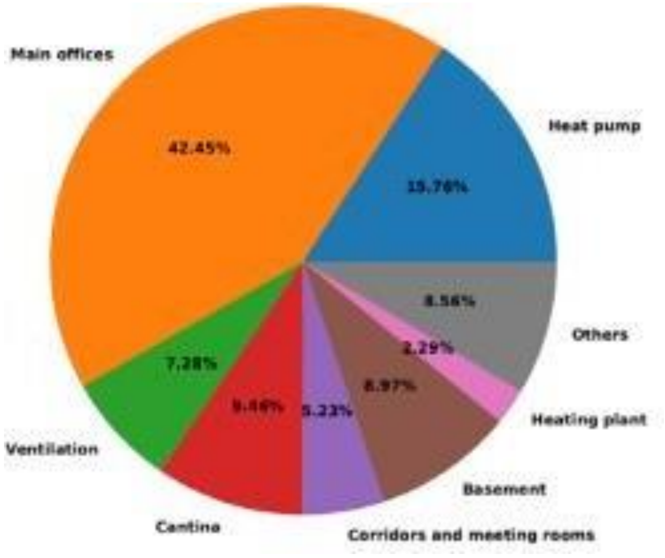


Figure 6. Electricity consumption in the office building [24].

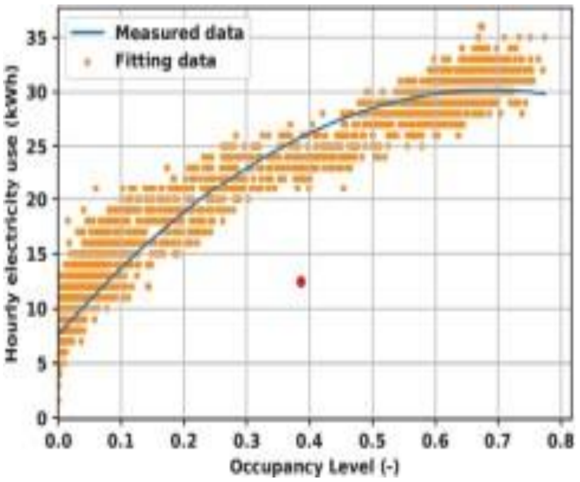


Figure 7. Electricity consumption of office vs occupancy [24].

As a conclusion of the paper, the results demonstrated the importance of energy control in offices buildings. The lack of control systems is identified as the cause of the large portion of energy wastage in these buildings. As an additional comment, the study also supports another statistical approach to reduce the energy use in public offices based on the calculation of the optimal stocking density, which other studies have found to be above the limit of 32 m^2 per person at which up to fifty percent of energy can be saved in comparison with lower density office buildings [25].

In the European Union, public buildings account for about 12% of the total number of public buildings [26]. However, in Belgium, they represent more than 30% of all buildings and are a more sophisticated sector than residential constructions.

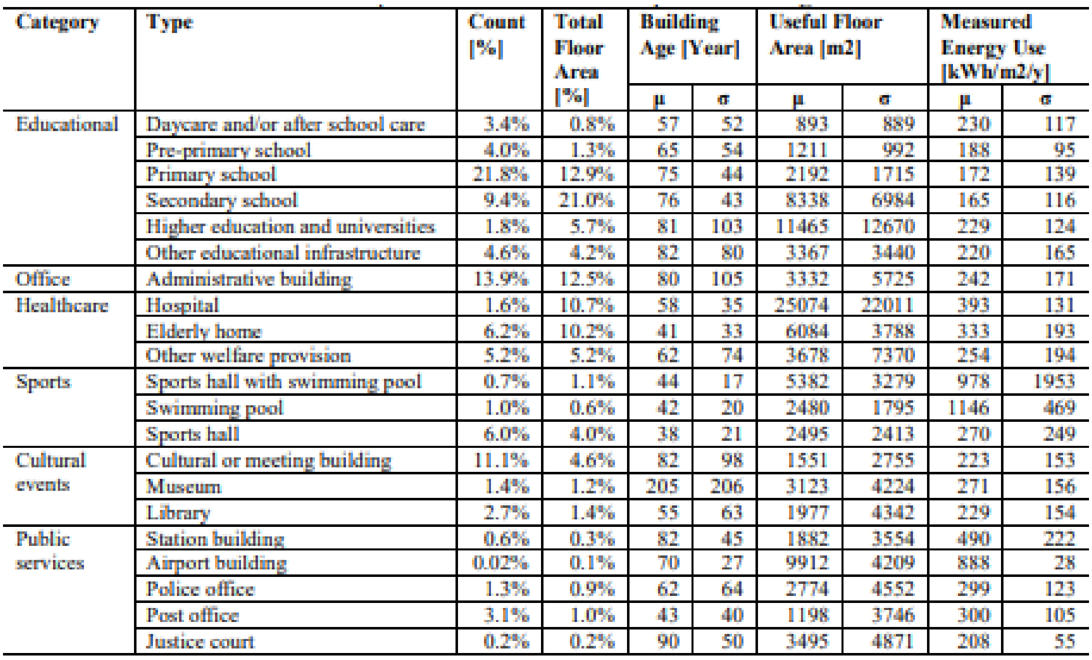
Moreover, 27% of the total primary energy consumption is to public, non-residential and commercial constructions. [27]. It was already established by the EU in the Energy Efficiency Directive (EED) and the Energy Performance of Buildings Directive (EPBD) that public and non-residential buildings would play an essential role for the 2050 targets and energy efficiency [28].

For these reasons, an investigation of Energy Performance Certificates (EPC) was carried out in Belgium on the basis of the publication of the database of public buildings containing about 10,000 samples, with the aim to identify and classify by statistical and cluster analysis inefficient buildings and to prioritise their renovation. This research is very similar to the purpose of this dissertation, as both documents aim to classify the buildings under study in order to find the inefficient ones and then propose measures to improve their classification in the Energy Performance Certificates.

In this research, it was proposed to define archetypes of non-residential building classifications in order to calculate their energy saving potential, focusing on offices, schools, hospitals, sports and cultural centres, and service buildings.

A methodology subdivided into three different analyses was employed: to start with, a descriptive analysis of the database, following that, a cluster analysis which is used with the aim to divide the sample set of the database into homogeneous groups. Finally, the energy performances were benchmarked to calculate the energy savings. Table 1 describes the statistics used from the database with their respective mean and variance, as well as the floor area as a function of their percentage and the percentage of buildings in each category in each classification:

Table 1. Descriptive statistics, Flemish non-residential buildings public database [29].



Category	Type	Count [%]	Total Floor Area [%]	Building Age [Year]		Useful Floor Area [m2]		Measured Energy Use [kWh/m2/y]	
				µ	σ	µ	σ	µ	σ
Educational	Daycare and/or after school care	3.4%	0.8%	57	52	893	889	230	117
	Pre-primary school	4.0%	1.3%	65	54	1211	992	188	95
	Primary school	21.8%	12.9%	75	44	2192	1715	172	139
	Secondary school	9.4%	21.0%	76	43	8338	6984	165	116
	Higher education and universities	1.8%	5.7%	81	103	11465	12670	229	124
	Other educational infrastructure	4.6%	4.2%	82	80	3367	3440	220	165
Office	Administrative building	13.9%	12.5%	80	105	3332	5725	242	171
Healthcare	Hospital	1.6%	10.7%	58	35	25074	22011	393	131
	Elderly home	6.2%	10.2%	41	33	6084	3788	333	193
	Other welfare provision	5.2%	5.2%	62	74	3678	7370	254	194
Sports	Sports hall with swimming pool	0.7%	1.1%	44	17	5382	3279	978	1953
	Swimming pool	1.0%	0.6%	42	20	2480	1795	1146	469
	Sports hall	6.0%	4.0%	38	21	2495	2413	270	249
Cultural events	Cultural or meeting building	11.1%	4.6%	82	98	1551	2755	223	153
	Museum	1.4%	1.2%	205	206	3123	4224	271	156
	Library	2.7%	1.4%	55	63	1977	4342	229	154
Public services	Station building	0.6%	0.3%	82	45	1882	3554	490	222
	Airport building	0.02%	0.1%	70	27	9912	4209	888	28
	Police office	1.3%	0.9%	62	64	2774	4552	299	123
	Post office	3.1%	1.0%	43	40	1198	3746	300	105
	Justice court	0.2%	0.2%	90	50	3495	4871	208	55

After applying the cluster analysis using the k-means method to all the building types present for each classification, the results in Table 2 show the optimal k values, the SC (silhouette coefficient, -1≤SC≤1) values and the centroids of the clusters formed in each category using the Z-Score and Min-Max methodologies. As can be seen, for the offices, several well separated clusters were formed as indicated by the SC value closer to 1 than -1. From the results obtained, the corresponding archetypes could be represented:

Table 2. Clustering results, Flemish non-residential buildings public database [29].

Category	**Type**	**Z-score method**			**Min-Max method**		
		k	***SC***	**Clusters**	***k***	***SC***	**Clusters**
Educational	Daycare and/or after school care	5	0.39	C1: 129, C2: 88, C3: 32, C4: 7, C5: 35	2	0.46	C1: 191, C2: 100
	Pre-primary school	4	0.36	C1: 26, C2: 68, C3: 209, C4: 58	2	0.48	C1: 276, C2: 85
	Primary school	4	0.37	C1: 147, C2: 1122, C3: 62, C4: 631	2	0.52	C1: 707, C2: 1255
	Secondary school	4	0.37	C1: 10, C2: 491, C3: 206, C4: 107	3	0.45	C1: 91, C2: 504, C3: 219
	Higher education and universities	4	0.44	C1: 38, C2: 15, C3: 9, C4: 99	3	0.48	C1: 108, C2: 15, C3: 38
	Other educational infrastructure	4	0.39	C1: 204, C2: 62, C3: 4, C4: 128	3	0.44	C1: 129, C2: 210, C3: 59
Office	Administrative building	5	0.48	C1: 784, C2: 74, C3: 8, C4: 314, C5: 22	2	0.61	C1: 324, C2: 878
Healthcare	Hospital	2	0.33	C1: 44, C2: 93	4	0.32	C1: 50, C2: 10, C3: 40, C4: 37
	Elderly home	4	0.34	C1: 176, C2: 290, C3: 4, C4: 58	2	0.46	C1: 196, C2: 332
	Other welfare provision	5	0.50	C1: 296, C2: 116, C3: 6, C4: 3, C5: 32	2	0.57	C1: 312, C2: 141
Sports	Sports hall with swimming pool	4	0.32	C1: 16, C2: 10, C3: 22, C4: 2	3	0.35	C1: 12, C2: 16, C3: 22
	Swimming pool	2	0.28	C1: 28, C2: 43	2	0.45	C1: 60, C2: 11
	Sports hall	6	0.43	C1: 185, C2: 285, C3: 17, C4: 34, C5: 1, C6: 2	2	0.53	C1: 322, C2: 202
Cultural events	Cultural or meeting building	5	0.47	C1: 616, C2: 43, C3: 224, C4: 2, C5: 48	2	0.59	C1: 689, C2: 244
	Museum	4	0.51	C1: 79, C2: 20, C3: 12, C4: 4	4	0.55	C1: 83, C2: 19, C3: 9, C4: 4
	Library	2	0.83	C1: 218, C2: 2	2	0.61	C1: 173, C2: 47
Public services	Station building	4	0.43	C1: 29, C2: 1, C3: 11, C4: 12	4	0.49	C1: 31, C2: 11, C3: 10, C4: 1
	Airport building	-	-	-	-	-	-
	Police office	2	0.43	C1: 87, C2: 20	2	0.53	C1: 87, C2: 20
	Post office	2	0.85	C1: 268, C2: 2	2	0.45	C1: 126, C2: 144
	Justice court	4	0.44	C1: 9, C2: 3, C3: 2, C4: 5	4	0.44	C1: 5, C2: 10, C3: 3, C4: 1

Table 3 concludes with the energy consumption results for each category, as well as their energy savings and floor area. From the results, it can be seen that educational and sports centres have the highest energy saving capacity due to their number and consumption respectively, while public services are more optimised. The energy saving capacity of each category is measured by the statistics: upper whisker, upper hinge, average, median, lower hinge. As the statistics increase, the energy saving capacity of the buildings increases.

Table 3. Energy saving capacity of each category, Flemish non-residential buildings public database [29].

Category	Current [MWh]	Upper Whisker		Upper Hinge		Average		Median		Lower Hinge	
		[%]	10^5*[m^2]	[%]	10^5*[m^2]	[%]	10^5*[m^2]	[%]	10^5*[m^2]	[%]	10^5*[m^2]
Cultural events	609.8	5.6	1.0	15.1	7.1	21.8	10.9	27.7	13.7	43.2	20.2
Educational	2797.1	4.9	7.6	12.9	36.9	16.8	53.4	21.8	74.6	33.8	116.4
Healthcare	3180.2	2.1	2.0	9.0	26.9	15.9	46.2	17.6	50.6	31.1	70.1
Office	1015.8	4.3	2.2	12.2	10.5	16.3	15.6	21.2	21.1	34.7	32.7
Public service	282.0	0.4	0.2	6.3	2.5	12.5	4.1	15	4.9	27.4	7.0
Sports	862.4	11.1	0.6	15.7	4.1	17.8	5.8	24.3	8.7	36.5	14.2
Total	8747.3	4.3	13.5	11.6	87.9	16.7	136	20.7	173.6	33.6	260.6

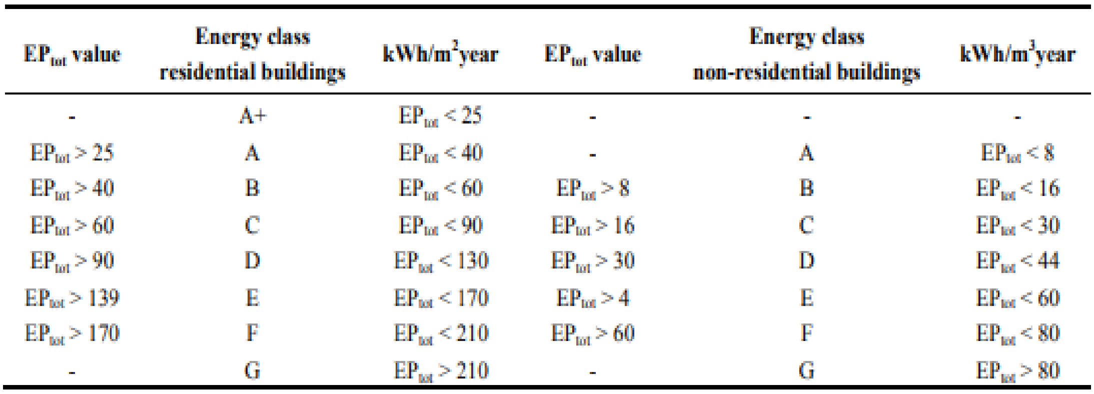
In the northern central Italian region of Emilia-Romagna, a statistical analysis was carried out with the aim of developing a regional energy system associated with the awarding of Energy Performance Certificates (EPC) and to study the possible actions to be taken to lower the energy rating of the buildings under study. These objectives are closely related to those proposed earlier in Chapter 1 of this dissertation.

The paper evaluates EPCs as a potential source of information to determine effective government policies and energy characteristics of buildings. With this goal, statistical approaches were carried out that helped to define EPCs as a statistical index of the energy rating of buildings from the regional database SACE (Sistema Accreditamento Certificatori Energetici) and then compared this energy index to the results obtained by bottom-up and top-down methods. These results would later be used to define different energy policies, applicable to different scenarios.

Upstream and downstream methods are commonly used in the disciplines of urban planning and large-scale energy sequencing by the European Union. The top-down or downstream method is also used in energy consumption studies oriented towards economic studies (e.g. financing and investment), while the bottom-up or upstream method is commonly used in energy efficiency studies of buildings.

In the Emilia-Romagna region, the energy performance certificate is expressed by the energy performance index or EPtot index, measured in primary energy (kWh/m^2*year for dwellings or kWh/m^3*year for other types of constructions), which is the pseudonym of the EPC scale used in Europe. As shown in Table 4, the EP scale in the Italian region differentiates between two main categories: residential buildings and non-residential buildings.

Table 4. Emilia-Romagna Region EP scale, energy performance certifications [30].



EP_{tot} value	Energy class residential buildings	kWh/m^{2}year	EP_{tot} value	Energy class non-residential buildings	kWh/m^{3}year
-	A+	$EP_{tot} < 25$	-	-	-
$EP_{tot} > 25$	A	$EP_{tot} < 40$	-	A	$EP_{tot} < 8$
$EP_{tot} > 40$	B	$EP_{tot} < 60$	$EP_{tot} > 8$	B	$EP_{tot} < 16$
$EP_{tot} > 60$	C	$EP_{tot} < 90$	$EP_{tot} > 16$	C	$EP_{tot} < 30$
$EP_{tot} > 90$	D	$EP_{tot} < 130$	$EP_{tot} > 30$	D	$EP_{tot} < 44$
$EP_{tot} > 139$	E	$EP_{tot} < 170$	$EP_{tot} > 4$	E	$EP_{tot} < 60$
$EP_{tot} > 170$	F	$EP_{tot} < 210$	$EP_{tot} > 60$	F	$EP_{tot} < 80$
-	G	$EP_{tot} > 210$	-	G	$EP_{tot} > 80$

For the case study, it was decided to sample from the SACE database the buildings belonging to the city of Verucchio. Constructions were classified into eight different categories according to their use: (E1) dwellings, (E2) offices, (E3) hospitals, (E4) recreational centres, (E5) markets/shopping centres, (E6) sport centres, (E7) schools and (E8) production buildings. Their energy ratings were compared to regional average values and the buildings with no energy rating were discarded. Figure 8 shows the primary energy consumption data for each building category:

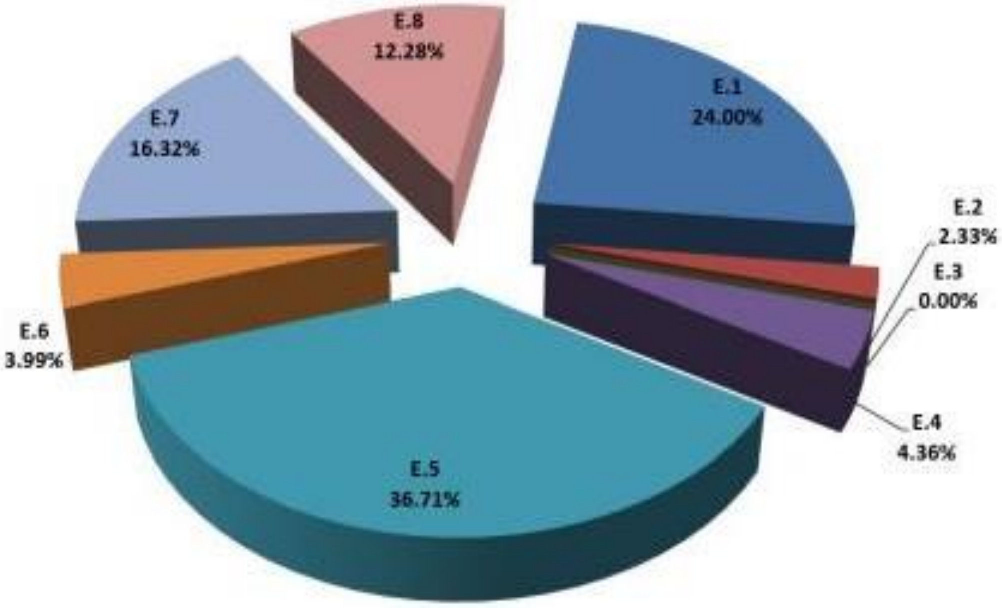


Figure 8. Primary Energy Consumption by building category [30]

In addition, the study considered that there might be a relationship between building category and the following variables: number of buildings with EPCs in each category, the average EPtot index rating (AIEPtot, Average Index EPtot) and volume (another different way of measuring floor area), so a graph was produced, Figure 9, where it can be seen how offices use a lot of primary energy per unit volume while markets/shopping centres, schools and production buildings are the most energy efficient.

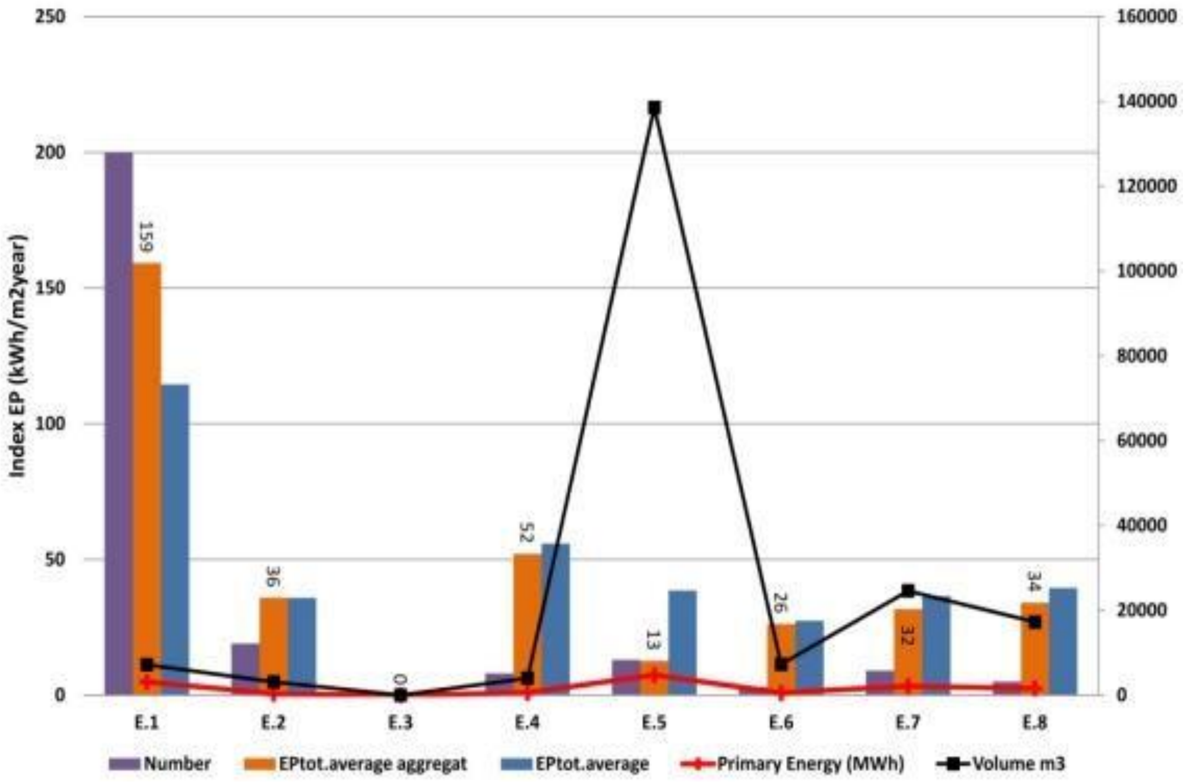


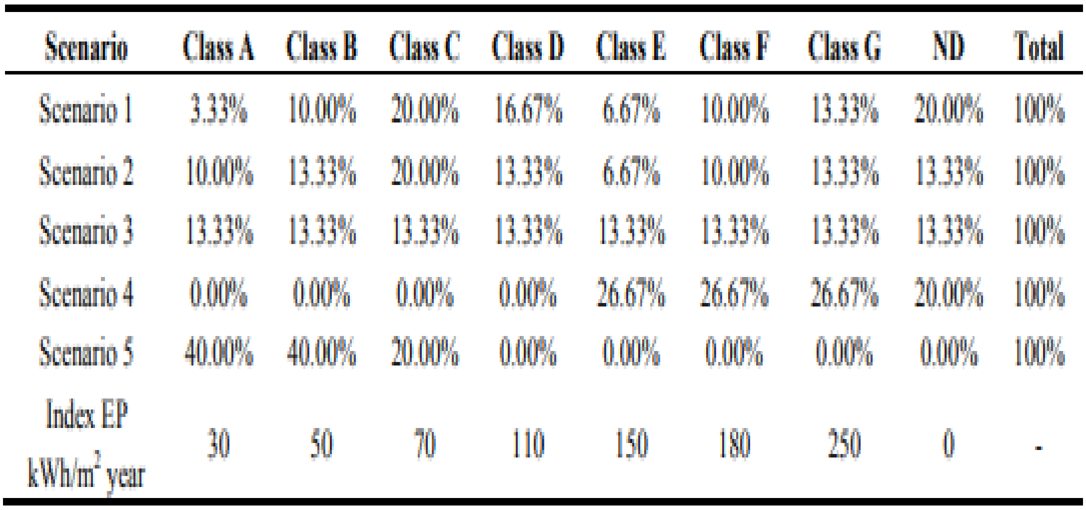
Figure 9. Building efficiency comparison [30].

Subsequently, in section two of the Italian paper, five different scenarios (Table 5) were described to simulate and statistically verify that they could be used to measure the energy saving capacity and actual energy status of EPCs, further classified according to the number of EPCs appearing in each class (from A to G including the extra class, ND), Table 6, in order to visualise their percentage distribution.

Table 5. Description of possible scenarios sharing new EPCs [30].

Scenario 1	New emission EPCs, distribution of energy categories equal to that of the database.
Scenario 2	Accidental subdivision of energy categories.
Scenario 3	Equal distribution of energy categories.
Scenario 4	Worst Scenario. New EPCs that belongs to energy categories E, F, G, and the extra ND.
Scenario 5	Best Scenario. New EPCs that belongs to energy categories A, B, C.

Table 6. Percentage distribution of EPCs belonging to each scenario according to their energy classification [30].



Scenario	Class A	Class B	Class C	Class D	Class E	Class F	Class G	ND	Total
Scenario 1	3.33%	10.00%	20.00%	16.67%	6.67%	10.00%	13.33%	20.00%	100%
Scenario 2	10.00%	13.33%	20.00%	13.33%	6.67%	10.00%	13.33%	13.33%	100%
Scenario 3	13.33%	13.33%	13.33%	13.33%	13.33%	13.33%	13.33%	13.33%	100%
Scenario 4	0.00%	0.00%	0.00%	0.00%	26.67%	26.67%	26.67%	20.00%	100%
Scenario 5	40.00%	40.00%	20.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100%
Index EP kWh/m^2 year	30	50	70	110	150	180	250	0	-

The final conclusion of the study summarises that, if the primary energy consumption of all constructions belonging to the shown categories need to be reduced in an effective way, then first of all, the factors and actors which affect the buildings must be studied in order to be able to propose realistic and efficient measures.

In the city of Novi Sad (Serbia), another study was carried out to determine if Energy Performance Certificates are relevant indicators of the actual consumption-savings of buildings. For this purpose, during the research, building stock certificates obtained from the District Heating System (DHS) database were compared with the results obtained from individual measurements of gas boilers in twenty buildings or Individual Gas Boiler (IGB) systems.

The cause-effect relationships of the Certificates with the building sector were identified through statistical analyses of the attitudes of owners/consumers, residents' associations, authorities with their policy plans and strategies, and energy companies. It was deduced that the actions of the companies are a fundamental factor in the research, development and investment of energy efficiency measures, as well as being key in the image and impulse that they generate for the assumption of these measures in the rest of the social actors.

In addition, a study of other implications derived from other research was carried out, where it was concluded that thanks to the EPCs, it is possible to monitor relevant aspects such as the health and well-being of the building's occupants, detect possible environmental impacts derived from the materials used during the construction period. The information from the Certificates corresponds to local socio-economic figures and could be used to identify areas at risk of fuel poverty.

Of the total number of 4067 buildings in the DHS database in Novi Sad, only 749 were in the category of business buildings, while the rest were residential buildings, so it was decided to study mainly this category.

The average total consumption data obtained from the DHS system (Q_{DHS}) was corrected to fit with the Energy Performance of Buildings Regulation (Q_{DHSc}):

$$Q_{DHSc} = Q_{DHS} * f \qquad \text{(Eq. 2)}$$

Where f is the correction factor calculated as:

$$f = \frac{HDD_{actual}}{2679} \qquad \text{(Eq. 3)}$$

Where HDD_{actual} is the actual heating degree days, and as the energy efficiency rulebook for buildings orders, the number of degrees for Novi Sad per day is 2679.

Samples of buildings belonging to both methods (DHS, IGB) were statistically analysed and eight representative buildings were chosen for graphical comparisons. Figure 10 shows the representative comparison of energies consumed in heat during the years 2018, 2019 and 2020 for both groups of buildings, those calculated by DHS and those obtained by IGB:

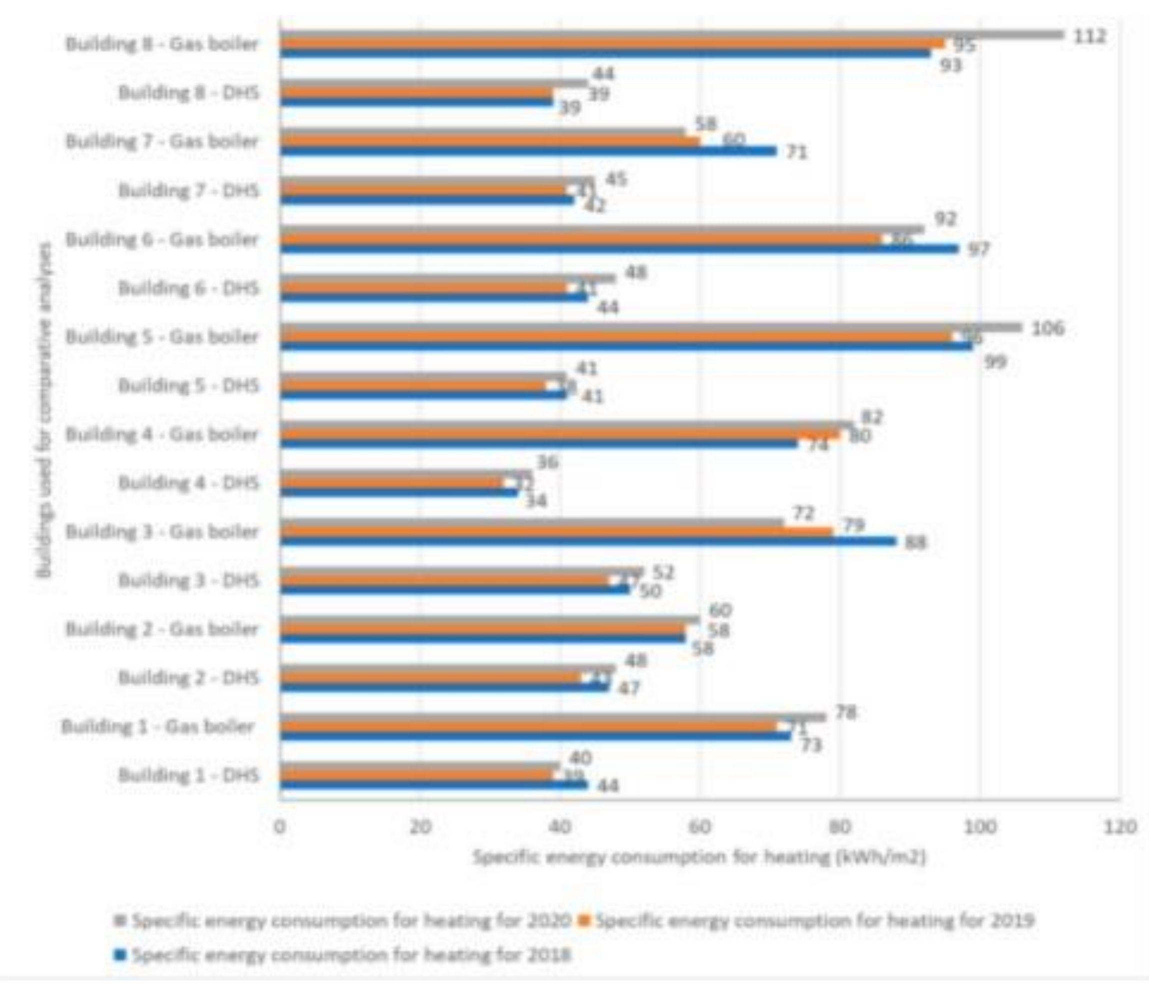


Figure 10. Comparison of energies consumed per heating during 2018, 2019 and 2020 for eight representative buildings [31].

As a conclusion of the analysis, both study groups show very different results in relation to actual energy consumption. The data obtained by the EPCs are lower than those measured by the energy metering system installed in the gas boilers.

Finally, this difference was attributed to changes in the design of the buildings during their construction that create differences between the actual surface to be heated and the previously assumed or theoretical surface to be heated. Therefore, the actual energy consumption of the buildings cannot be expected to be identical to the theoretically measured one and therefore the need to use metering systems in buildings as a measure to ensure efficient energy consumption becomes more evident.

In 2018, in Switzerland, an evaluation of the heat performing status of domestic buildings was carried out by means of a statistical analysis of EPCs [32]. This was formulated in the framework of the Swiss Energy Strategy 2050 [33], which is directly linked to the EU Decarbonisation Strategy 2050.

It was noticed that there was a need to decrease the energy consumption of buildings due to the fact that they consumed about 45% of all energy used in the country. For the analysis it was decided to take an evaluation methodology based on the characterisation of residential buildings from the outset into smaller sample groups through the statistical study of their EPCs and, for each of these groups, to define a residential building archetype on which to apply the simulations and consequent measures to improve energy efficiency. One takes note of this methodology as it can also be used for our analysis of Maltese offices.

The objective was to find the unused energy saving capacity for the further renovation of the buildings. About 10,500 energy certificates from buildings all over the country were analysed. In addition, the study of building parts as walls, roofs, floors and windows was deepened investigated, as it is fundamental to calculate the thermal energy rating of the building. In the statistical analysis, the climate factor was included as a significant variable in the problem, because when sampling residential buildings from all parts of the country, the climatic zones to which each building belongs must also be considered.

Given the final outputs of the study, it was shown that the energy rating of three quarters of all buildings in the study was below the average of most newly constructed buildings of the last two decades, as shown in Figure 11. In this way, it was shown that buildings have a high, until then unexploited, capacity for reconversion and energy savings that needs to be exploited to achieve decarbonisation and zero emission targets.

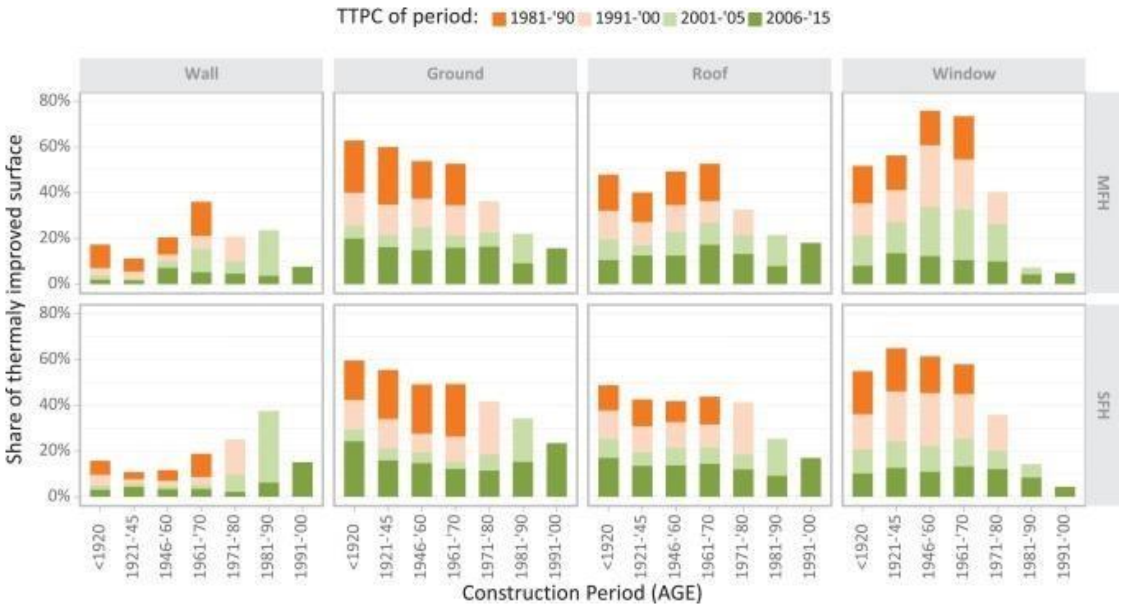


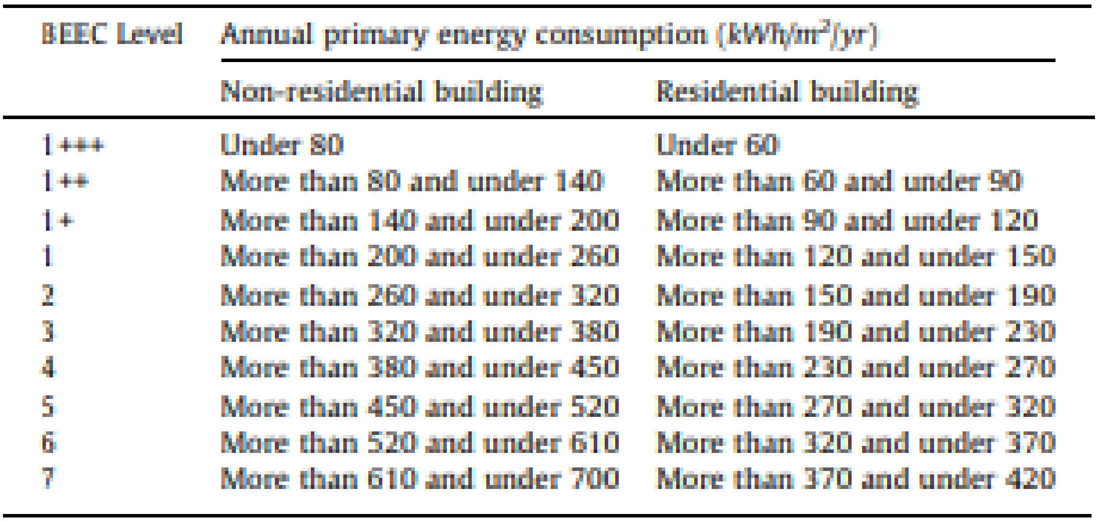
Figure 11. Unexploited capacity of saving energy of Swiss residential buildings [32].

2.1.2 CASE STUDIES OUTSIDE THE EU

In 2020, the Ministry of Land, Transport and Infrastructure (MOLIT) of South Korea after reviewing the First National Plan [35]. In line with the targets set by other countries, it developed the Second National Green Building Plan [36], which included numerous policies to decrease energy use in domestic and non-domestic buildings.

This study by South Korean researchers aims to analyse the building energy efficiency certificates (BEECs) of a sample group of almost 223,000 non-domestic edifices from the Korean National Database (KNDB) [34], owing to understand the effect of the energy efficiency and environmental policies implemented by the South Korean government in recent years. Table 7 and Figure 12 compare the values of the South Korean BEEC and Maltese EPC energy efficiency certifications for dwellings further clarification:

Table 7. Criteria for Buildings Energy Efficiency Certificate (BEEC) [34].



BEEC Level	Annual primary energy consumption (kWh/m²/yr)	
	Non-residential building	Residential building
1+++	Under 80	Under 60
1++	More than 80 and under 140	More than 60 and under 90
1+	More than 140 and under 200	More than 90 and under 120
1	More than 200 and under 260	More than 120 and under 150
2	More than 260 and under 320	More than 150 and under 190
3	More than 320 and under 380	More than 190 and under 230
4	More than 380 and under 450	More than 230 and under 270
5	More than 450 and under 520	More than 270 and under 320
6	More than 520 and under 610	More than 320 and under 370
7	More than 610 and under 700	More than 370 and under 420

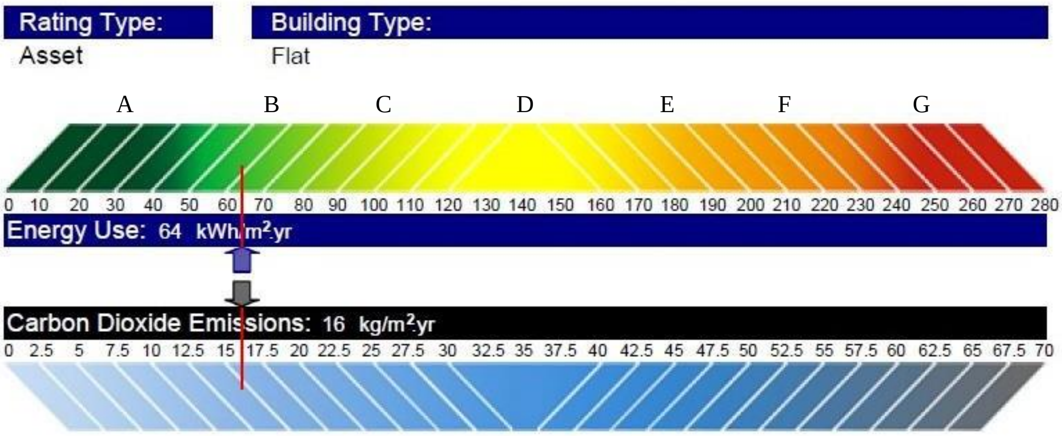


Figure 12. Criteria for Energy Performance Certificate (EPC) [37].

The study was carried out using a proprietary statistical methodology where initially the actual energy use index or EUI was compared with the EUI of the certificates. Given the results of this comparison, it was shown that the data obtained for the actual EUI was higher than that of the certificates. Moreover, as the degree of certification increased (improved) the difference was much more significant (e.g. the difference for a BEEC 2 energy rating was 15%, while for buildings with a BEEC 1+++ rating, the difference was more than 60%).

In the second part of the paper, the same comparison was made, but between the EUI obtained from certified buildings and the EUI of non-certified buildings, revealing that certified buildings provided better data (up to 58% less energy consumption) which implies that Building Energy Efficiency Certification(BEEC) greatly supports the energy savings of certified buildings compared to non-certified ones, demonstrating that the technologies employed in energy savings pay off economically in the long term and are effective.

Figure 13 below provides the comparison of the energy intensity consumed in certified constructions with non-certified cosntructions belonging to groups A (pre-2011 buildings) and B (post-2012 or newly constructed buildings):

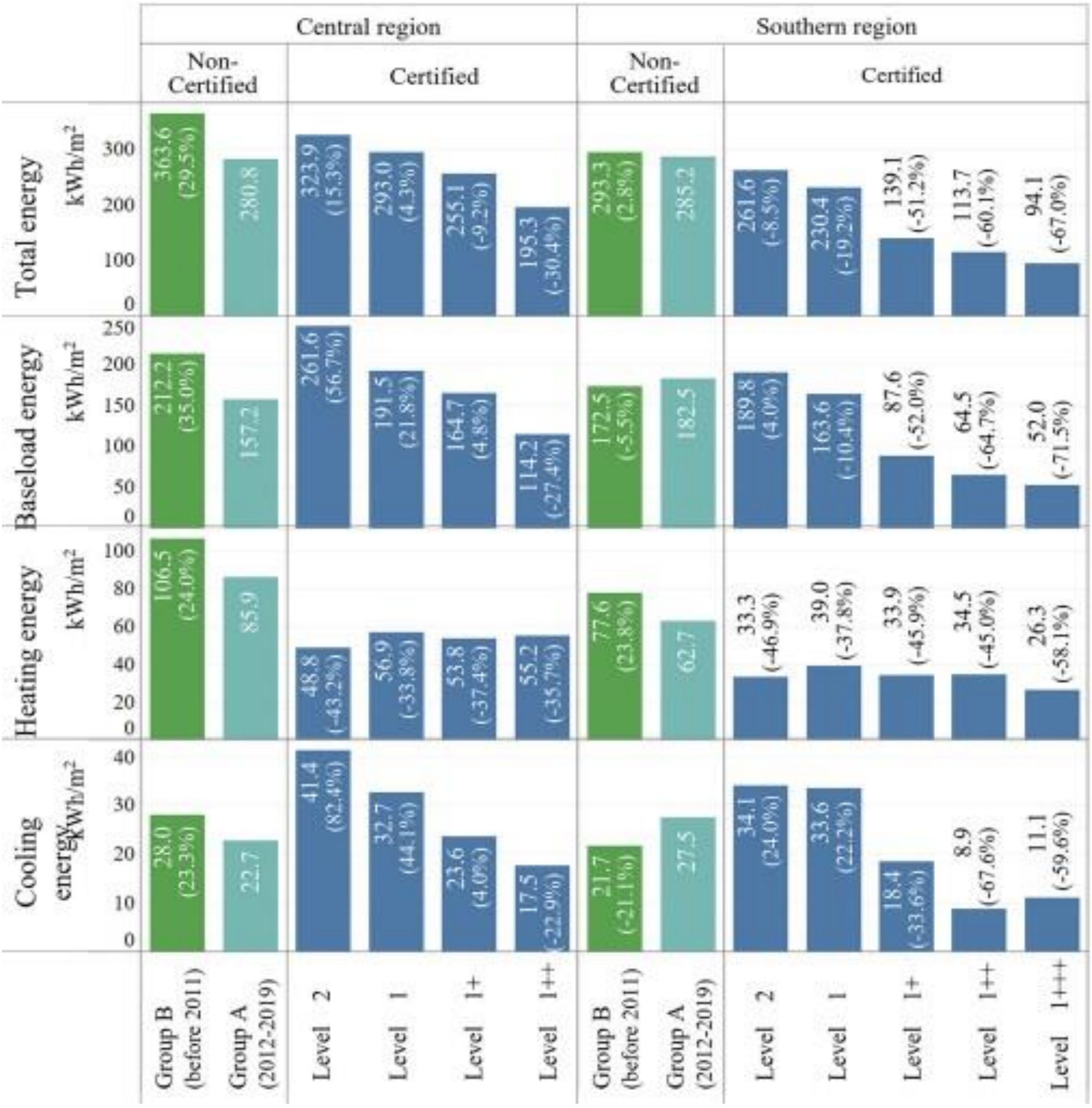


Figure 13. The actual median value of the EUI for certified and non-certified buildings [34].

In Australia, a study of a reference commercial office in Brisbane and Hobart was carried out using metaheuristics based on animal behaviour. Specifically, the researchers developed a new methodology based on the Ant Colony Optimisation Algorithm for Mixed Variables (ACOMV) [38], coupled with building simulation software, as these algorithms are seen to be able to continuously handle large amounts of compensations in the design of the model. The main problem one observes in the use of these algorithms for dissertation application is related to the complexity of the algorithm itself, the non-linear behaviour, the increase in time required to develop a suitable model and the high computational costs associated with solving building optimisation problems [39].

The office building optimisation problem was approached taking as a premise the uncertainty of the problem parameters themselves, since the energy consumption of the building involves many unknown or uncontrollable variables (e.g. the building's own construction materials, internal loads, building operation or changing climate). Therefore, the study assumes that, due to the dependence of energy consumption on the variables, any optimum actually found is sub-optimal given all actual parameters [38]. In other words, the performance gap already mentioned in several studies, where the theoretical optimal rendition of a building is compared to the real optimal performance obtained, would be observed again [40], [41]. For this reason, the Modified Ant Colony Optimisation Algorithm for Mixed Variables or ACOMV-M was created, with the objective of resolving as far as possible the uncertainty that belongs to the construction parameters and to reduce the computational cost of the analysis, increasing the search for the optimum in the final stages of the optimisation of the model.

The new algorithm developed by the researchers was called ACOMV-M, or Modified ACOMV, and the simulations performed with this new mathematical method were compared with those performed with the ACOMV and PSOHJ (Particle Swarm and Hook Jeeves Hybrid Optimisation) methods commonly used in Building Optimisation Problems (BOP).

After performing the required experiments, the results of the three algorithms were compared in terms of energy used, as shown in Figures 14 and 15, demonstrating that the one developed by the researchers obtained better results by obtaining a higher energy saving in the last iterations to locate the optimum. In terms of convergence speed, it was shown that the modified algorithm was much more efficient than the other two, using up to half the number of simulations.

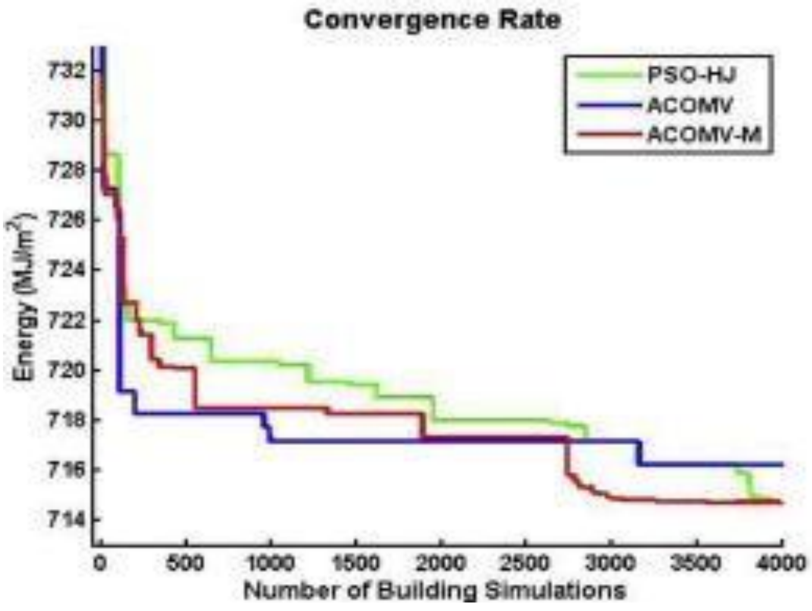


Figure 14. Convergence solution for Brisbane Office Building [38].

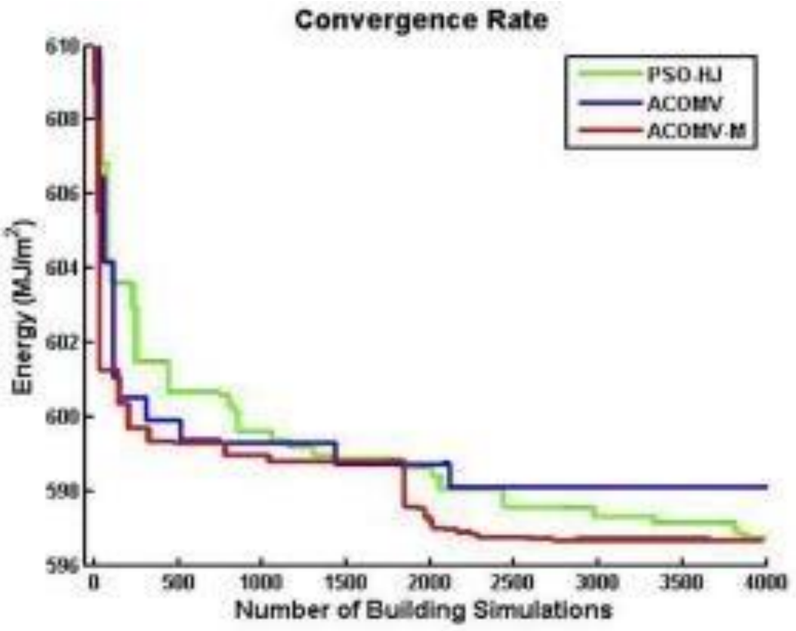


Figure 15. Convergence solution for Hobart Office Building [38].

The research was concluded with results in the range of [20-26] % energy savings for the Brisbane and Hobart office building model, respectively.

Additionally, in terms of design parameters, it was concluded by the researchers that sacrificing this uncertainty provides optimal results with a performance gap not bigger than 5%, which compensates by avoiding the computational complexity, time expenditure and development of complex mathematical optimisation methodologies. However, it is true that energy savings can increase as more variables and parameters are taken into account when designing the model.

2.1.3 CASE STUDIES IN MALTA

In Malta, most of the residential and non-residential buildings were built during the colonial period under British control during the 1800s until its recent independence in 1964 [42], which implies that the construction methodology of these buildings cannot be grouped into a single classification if they will be studied in terms of characteristics like the raw materials used for construction. Moreover, it is evident that the methodologies used to build these building stock are far from being equal to each other and also far from those used to construct the more modern and new buildings.

It is also important and should be noted that after Malta's adhesion to the European Union in 2004, the Energy Performance of Buildings Directive, EPBD, was finally implemented as the other Member States [43], which means that all those buildings built before this point, in principle, are not in an optimal state under the eyes of the Directive because the legislation requirements such as minimum energy performance limits were not taken into account.

It has been shown in recent studies [44], that different specific measures have an influence on the Energy Performance Certificates (e.g. cooling systems, heating, implementation of photovoltaic systems, underfloor heating or/and water heating). Therefore, it is necessary to apply statistical analyses in order to reference the buildings properly as the current energy certificates are based on energy efficiency to declare the actual state of the building.

For any statistical analysis that evaluates the energy optimisation of new or renovated buildings, the main objective is based on obtaining results close to or equal to the zero energy status, in line with guidelines of the Energy Performance of Buildings Directive (EPBD). Therefore, benchmarks based on the current state of the construction are required owing to subsequently evaluate the possible applicable steps and improve the energy rating of the building, where they must also be studied from a financial profitability point of view.

Another study carried out in the Mediterranean archipelago investigated the optimal energy cost rates for new office buildings following the Energy Performance of Buildings Directive, EPBD 2010/31/EU [45]. In this research carried out recently in 2018, delivered and reviewed by the Malta Building Regulation Office, an attempt was made to define the minimum energy performance requirements taking as a reference the methodological framework to calculate the optimum cost pertaining to Regulation number 244/2012 [46].

The methodology used to define and classify offices into different categories or groups as representative and benchmark, with the aim of obtaining representative buildings for each of the categories, is shown below. This methodology will be important as it proposes a similar structure and working model to what is being looked for so it can be used as a reference in the dissertation.

In Table 8 below, two reference buildings were selected based on typical existing models in Malta, each separated in three different categories by floor area.

Table 8. Definition of Reference Buildings [45].

Reference Buildings	Floor Area
Detached Offices	< 500m^2
	500m^2< / <1500m^2
	>1500m^2
Terraced Offices	< 500m^2
	500m^2< / <1500m^2
	>1500m^2

The fact that this study classifies the reference buildings into six new categories according to their floor area is a very interesting idea that will be noted for establishing the methodology and the statistical analysis of the dissertation since, as will be seen below, in the database provided by the University of Malta for the study. In fact, the main and almost unique characteristic by which the offices can be differentiated is the floor area.

In addition, in accordance with the newly defined reference buildings, six building models were designed as similar as possible to real existing office buildings in order to achieve a statistically representative analysis and to meet the characteristics proposed above. These buildings are summarised below in Table 9.

Table 9. New Reference Office Buildings with floor area, number of floors and total area [45].

New Office Buildings			
Reference Office Building	Floor Area (m^2)	Number of Floors	Total Area (m^2)
Detached Office 1a	112.5	2	225.0
Detached Office 1b	450.0	2	900.0
Detached Office 1c	821.0	2	1642.0
Terraced Office 2a	123.0	2	246.0
Terraced Office 2b	167.0	3	501.0
Terraced Office 2c	493.0	4	1972.0

To continue the analysis, specific energy efficiency measures and combinations of these measures were defined for each reference office building in order to achieve energy efficiency. The combinations were carried out with the measures in the following areas: heating systems, cooling systems, water systems and renewable energy systems. In total, 72 combinations were carried out.

For each of these combinations the primary energy (kWh/m^2*year) was evaluated using the software SBEM-mt (Simplified Building Energy Model for Malta). The overall costs (€/m^2), the optimal costs (overall cost/primary energy) and different types of discount rates were applied.

Finally, after determining all the results of applying the different energy efficiency packages and their corresponding life cycle (global) costs, these were plotted to determine the least costing measures and the corresponding energy rating. Figure 16 shows the result of the statistical analysis for the evaluated simulations belonging to the reference building Detached Office 1A.

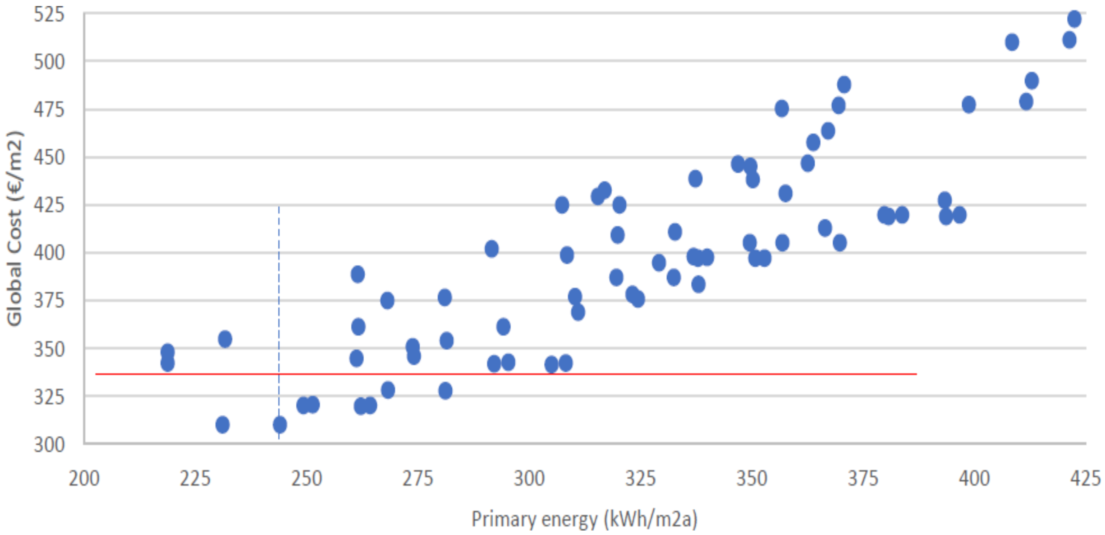


Figure 16. Optimal cost, global cost/ primary energy for New Detached Office Building 1A [45].

As final results, all optimal cost ranges for each reference office building were aggregated, as shown in Figure 17, which supports the new cost optimal and EPC classifications of the new offices.

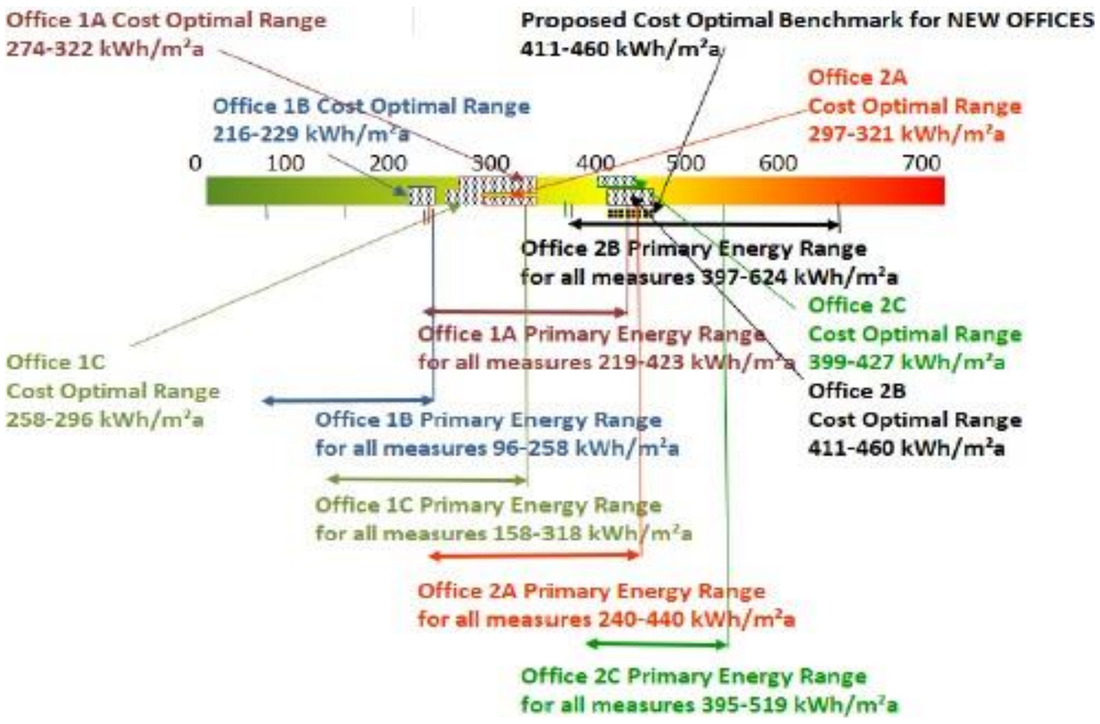


Figure 17. Results obtained after evaluating the optimal cost of all proposed new offices reference buildings [45].

On the other hand, it was proposed to study from a macro-economic point of view the future optimum cost ratings to be used as reference values since they usually offer more insight into the impact on optimal primary energy caused by discount rates, price developments and the financial perspective itself, although in the authors' view this impact is minimal. In addition, results were attached which show the large gap between the optimal cost of office buildings with renewable energy systems and buildings without, with photovoltaics being the recommended energy source for national energy cost classifications.

Furthermore, since the EU Cost Optimum Regulation dictates that it is the responsibility of the Member States to calculate the weighting of the reference factor relative to the importance of the reference buildings used in each country [47], as a recommendation of this paper it is suggested to use an energy efficiency benchmark for new offices based on the cost-optimal office building range: Terraced Office 2B.

In a different study carried out by the University of Malta as a final degree project by a student from Spain, Valladolid. A statistical analysis of EPCs was carried out with a focus on Maltese dwellings with the aim of determining possible options for improving the energy ratings of the different groupings or classifications of dwellings used for the analysis [48].

Following the first investigation, eight different types of dwellings were recognised into which the observations could be classified:

1. Bungalow
2. Duplex Flat
3. Flat
4. Full Detached Dwelling
5. Semi Detached Dwelling
6. Maisonette
7. Penthouse
8. Terraced house

These are further classified according to the information in the database into two distinct groups: dwellings under design i.e. new and not yet built and asset or existing dwellings.

This last type of classification is the same as the one that can be used in this dissertation, as in our database the main information besides the Floor Area to differentiate the offices is their categorisation as Building in Design or Asset.

However, after analysing a cost-optimal study for dwellings in Malta [49] and comparing it with the documentation provided by the Government for the Zero Energy Plan [50], it was observed that there was no common classification for dwellings.

Therefore, a new balanced classification was made against both documents and against the initially submitted classification itself:

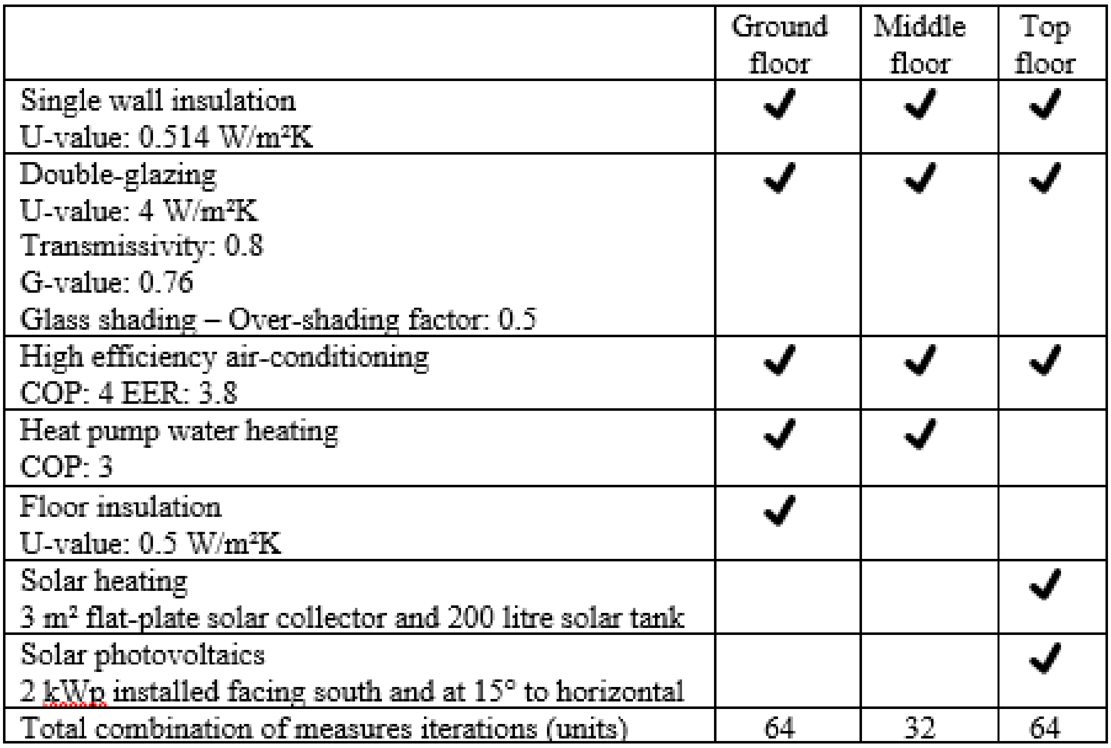
1. Bungalows
2. Ground floor flats
3. Middle floor flats
4. Top floor flats
5. Full Detached dwellings
6. Semi Detached dwellings
7. Terraced house

After carrying out the relevant statistical analyses and tests, very interesting results were obtained. It was shown that not all dwellings can be grouped into the same energy classification, but that it is necessary to study them separately and apply measures individually to each group in order to be able to make effective improvements in their classification.

In addition, due to the large number of outliers omitted during the study, it was proposed that the quality control of the EPC data collection should be improved, as this would help to make faster progress in the energy evolution and adjustment of the country to the zero-energy plans initially proposed by the EU.

Finally, as a main part of its objective (which coincides with the one proposed in this dissertation), as shown in Table 10, measures to improve energy efficiency were proposed:

Table 10. Accepted measures applied to flats to improve their rating in energy performance certificates [48].



	Ground floor	Middle floor	Top floor
Single wall insulation U-value: 0.514 W/m²K	✓	✓	✓
Double-glazing U-value: 4 W/m²K Transmissivity: 0.8 G-value: 0.76 Glass shading – Over-shading factor: 0.5	✓	✓	✓
High efficiency air-conditioning COP: 4 EER: 3.8	✓	✓	✓
Heat pump water heating COP: 3	✓	✓	
Floor insulation U-value: 0.5 W/m²K	✓		
Solar heating 3 m² flat-plate solar collector and 200 litre solar tank			✓
Solar photovoltaics 2 kWp installed facing south and at 15° to horizontal			✓
Total combination of measures iterations (units)	64	32	64

In terms of research findings, it was observed that the total number of flats had the capacity to improve their energy rating to A levels (near zero emissions) within their respective category, implying that the benefits derived from the implementation of the energy plans for flats in Malta have the potential to be greater than initially expected.

Furthermore, it was shown that the use of a reference building for each classification would greatly facilitate the statistical study of the different categories, as well as further economic studies that would also have an impact on the measures implemented for the improvement of EPCs [48].

Another research has been carried out in support of two main objectives for the successful inclusion of certificates in society: promoting their attractiveness and increasing control over their evaluation and improvement process [51]. For the attractiveness and social acceptability of certificates, other methods of providing information to the public were developed, e.g. colour assessment associated with energy performance certificates, where the greener means (colour associated culturally and psychologically in Europe with benefits) the better (lower) and the redder means (colour associated culturally and psychologically in Europe with harm) the worse (higher).

In another study carried out in Spain [52], the statistical cluster analysis methodology was implemented to analyse the EPCs of constructions belonging to the residential category. In this analysis, clusters were used as attributes for which their correlation was established by also applying the k-means term. In addition, the energy certificate benchmarking method of the Spanish rating procedure and associated Technical Building Code (TBC) [53] may also be used, adapting it to the needs of the dissertation. Moreover, in Spain the energy performance certificate ratings are the ratio between the stipulated rating for each category and the actual rating of the building.

2.2 SUMMARY

As one has noticed during the reading of Chapter Two on Literature Review, there are not many specific studies available on offices as most studies in the literature focus more on dwellings as they form a very large percentage of the total building stock. This difficulty has led to the need to investigate more deeply to find any studies on offices and after that focus the rest of the research on studies carried out on dwellings that could be useful for this dissertation.

In summary, in Chapter II, various research studies both external and internal to the EU have been studied, in addition to those pertaining to Maltese territory. This intensive study has been carried out in order to obtain different conclusions from different studies that could help to enhance the quality of research and expand the background for the dissertation. The following are some of the main conclusions that have been obtained.

As a main conclusion, we find the fact that controlling the energy consumption of homes, schools, hospitals, offices [24] ... is an imperative for Nearly-Zero Emissions targets set by the European Union and all member countries [28]. In the same way, consumers must know the energy status of their buildings and how they can actively participate in the improvement [51]. In addition, certified buildings provide better energy consumption data than non-certified buildings [34].

However, in research that has been carried out to determine the efficiency of EPCs by comparing them with very accurate and real measurement systems of water and gas boilers (in the same buildings) [31], it has been shown that EPCs tend to give energy consumption results below real-time measurements. In these facts, the need for EPCs is demonstrated, but also the need to create a control system for certifications linked to their continuous improvement and inspection.

According to the Energy Efficiency Directive (EED) and the Energy Performance of Buildings Directive (EPBD), non-residential buildings will contribute significantly to achieving the 2050 targets [28]. Furthermore, it is known that, of the non-residential buildings, the office category is paramount for Malta as it occupies a large part of the total stock [45]. However, no attention is usually paid to the study of energy efficiency in offices with most of the research being focused on dwellings.

Finally, it was shown that the use of reference buildings to study the classifications or clusters greatly facilitates subsequent statistical analyses, as well as any subsequent economic study to be carried out, as well as the proposal of measures and recommendations to improve the ratings of the certificates [48].

CHAPTER 3: METHODOLOGY

3.1 STATISTICAL ANALYSIS OF EPC GUIDELINES AND METHODOLOGY

Since the first EPCs were introduced on the market in 2009, both the energy rating criteria and the measures and recommendations proposed to improve these ratings have been improved and evolved. The process of developing these certifications has been continuously redesigned to offer the best possible support to Europe's energy plans [54].

The main method of analysing data pertaining to EPC certificates is based on initially removing outliers that may have been erroneously introduced into the base data to be used. Several studies agree on a specific methodology to detect these outliers in order to proceed to their elimination such as the: Box and Whiskers Plot [48], but there are other formal statistical methodologies that can also be used for the same aim. These methodologies will be presented below.

Secondly, observations are usually grouped into clusters that share common characteristics, so that the number of similar observations and how they differ from each other can be easily differentiated [55]. In the case of this dissertation, the main or most important clusters to be carried out will be based on the type of energy certificate issued, with Asset Rating implying the building is in existence and Design Rating, which means that the building is not yet built. Moreover, clustering will be used based on the total floor area [56].

Finally, the first step will be to study if the office stock provided in the database is energetically efficient, i.e. if there is a higher number of offices with class A, B, C certifications or otherwise D, E, F, G (if the office stock is not energetically efficient). In this way, a broader view of the causes of inefficient offices will be obtained and finally, actions to get better the energy ratings of the stock can be studied.

3.1.1 GEOGRAPHIC LOCATION AND CLIMATE CONDITIONS.

For this dissertation, it is assumed that all offices in Malta are subjected to the same outdoor climatic conditions. This is because of the small size of the country and the absence of significant physical changes such as topographical differences. The Republic of Malta is an archipelago of islands located in the centre of the Mediterranean Sea, south of Sicily and north off Libya, and its climate classification according to the Köppen-Geiger method is related to the colour yellow: Csa, which determines a climate of moderate temperatures, with generally moderate temperatures and rain in winters with hot dry summers [57].

3.1.2 DESCRIPTION OF OFFICES.

An office is a local establishment, which usually belongs to a company or self-employed professional, where a large part of the total business, services or manufacturing activity is carried out. Offices, unlike other types of buildings, e.g. dwellings in Malta which are easily differentiated into bungalow, duplex flat, flat, villa, duplex, penthouse, townhouse or semi-detached house [48], can all be included in the same general category, and therefore, in this dissertation it will be proposed to differentiate them by two main characteristics:

1. Separation according to their energy performance certificate type:

   a. Asset rating for existing offices.

   b. Design rating for new offices.

2. Separation according to floor area.

The second clustering has been proposed for two key reasons; the first reason is the inability to group all offices in the same cluster when they all differ enough in size from each other as the conclusions and results of the statistical analysis would not be significant for further studies. The second one is the need to apply a different method of differentiation and classification between groups of offices, as only having a classification based on whether the office exists or is new construction does not provide information about how the floor area variable affects the energy efficiency status of the offices.

Moreover, if measures to improve the energy efficiency of the office are subsequently implemented and any of these are directly or indirectly dependent on the office floor area or are not economically feasible for high floor area or low floor area offices, the information needed to justify these conclusions during the study would have been lost.

One of the main differences between a large floor area office and a small floor area office is their floor layout. While small offices are usually distributed in small rooms, like a dwelling, larger offices, such as the one shown in Figure 18, are open plan with many desks distributed inside.

Figure 18. Floor plan layout of a large office.

As a final comment, other possible techniques should be recognized that might be more useful, depending on the office case to be analyzed as this dissertation argues that the offices to be analyzed fulfil only the role of offices and are all on one floor.

Other types of clustering methodologies could be used if, for example, part of the offices to be analyzed serve only as offices while others are part of a conference room, if the office is a converted building (change of use) or is a new building, if there are offices with a larger number of floors or depending on the building materials. For each difference of characteristics that influence the statistical analysis and the parameters of the simulation software, own clusters should be created where appropriate comparisons between offices of the same type can be made.

3.2 METHODOLOGY APPROACH FOR THIS DISSERTATION

The analysis of this work focuses on offices which form 18.594% out of a total of 3157 EPC certificates covering twenty different non-dwellings categories, as obtained from the national EPC database of the Building and Construction Authority and covering the period 2009 to 2018. The database to be analysed contains a total of 587 Office EPCs, and the first step will be to subdivide them into smaller groups by classifying them according to their main characteristic, namely their Floor Area. After a detailed analysis of the Malta Nearly Zero Energy Plan [50], the only reference to a classification scale for offices together with their recommended primary energy for energy performance certificate values has been obtained, as shown in Figure 19 below.

Reference building	Current Requirements (kWh/m2yr)	Cost-optimal level without Photovoltaic systems (kWh/m2yr)	Gap between current req. & cost opt. w/o PV systems kWh/m2yr	Gap %
Detached Office <250m2	372.9	269.8	103.2	28%
Detached Office 250m2-1500 m2	279.8	215.7	64.1	23%
Detached Office >1500m2	338.65	199.1	139.6	41%
Terraced Office <250m2	419.8	305.7	114.1	27%
Terraced Office 250m2 - 1500 m2	378.1	290.9	87.2	23%
Terraced Office >1500m2	352.1	280.2	71.9	20%
Mixed Use Office <250m2	382.1	288.6	93.4	24%
Mixed Use Office 250m2 - 1500 m2	367.4	203.5	163.8	45%
Mixed Use Office >1500m2	318.1	248.3	69.7	22%
Average	**356.5**	**255.7**	**100.7**	**28%**

Figure 19. Classification of non-dwellings (offices) according to the Nearly Zero Energy Plan for Malta [50].

In the same way, the cost optimal study for new offices in 2018 has followed a similar trend [45], by differentiating between Detached Offices and Terraced Offices, but applied different floor area ranges when creating the subgroups according to Floor Area. In other studies, analysing the whole spectrum of non-dwellings [58], offices were only classified according to whether the building was fully comprising of offices or whether it is a mixed use building with 50% or more of the floor area assigned to office space.

However, as explained before, given that the information necessary to differentiate between Detached or Terraced Offices (or other different type of classification) is not available in the national database, this dissertation will not be able to take these categories into account and will therefore assume the classification based only by floor area for future simulations and statistical analysis.

It has been decided to separate the total number of offices into four initial clusters, as shown in Table 11.

Table 11. Initial division of office stock by floor area.

Categories	Floor Area (m^2)	Total Number of EPCs
O1	(1 - 250]	354
O2	(251-500]	63
O3	(501-1500]	99
O4	(1501+]	71

As previously mentioned, the age of the building is not known or specified in the database, so these same categories will be subdivided according to the actual information obtained. In this case, the new subcategories will be Design or Asset Rating. In this way, eight differentiated clusters of offices will be obtained, as can be seen in Table 12 below.

Table 12. Secondary division of the office stock according to its Design or Asset Ratings.

Categories	Floor Area (m^2)	Total Number of EPCs	Age	Number of EPCs
O1	(1 - 250]	354	**Design**	91
			Asset	263
O2	(251 - 500]	63	**Design**	9
			Asset	54
O3	(501 - 1500]	99	**Design**	25
			Asset	74
O4	(1501+]	71	**Design**	24
			Asset	47

3.2.1 OMISSION OF OUTLIERS

Following the first phase of classification of the offices, the samples obtained from the database will be statistically analysed to control the introduction of outliers in the subsequent analysis. The presence of one or more outliers among the data can produce serious problems and distortions in the analyses of the model, especially the variance would be affected. In the large majority of situations, the introduction of outliers into the model is due to human error while performing calculations or introducing and coding the samples for the final database [59]. In the case of this dissertation it is most likely to be due to data introduction error, due to the fact that it is not planned to carry out statistical experiments as fitted models or simulate with response surfaces that can introduce outliers by other ways. During the dissertation, it will simply handle individualised offices data and apply statistical techniques like simple regressions.

To detect these "absurd" and unusual values, various formal statistical procedures can be applied, e.g. a rough outlier check can be performed by examining the standardised residuals [60], as shown in Figure 20, where any residual above ±3 or ±4 bands would be considered as a potential outlier.

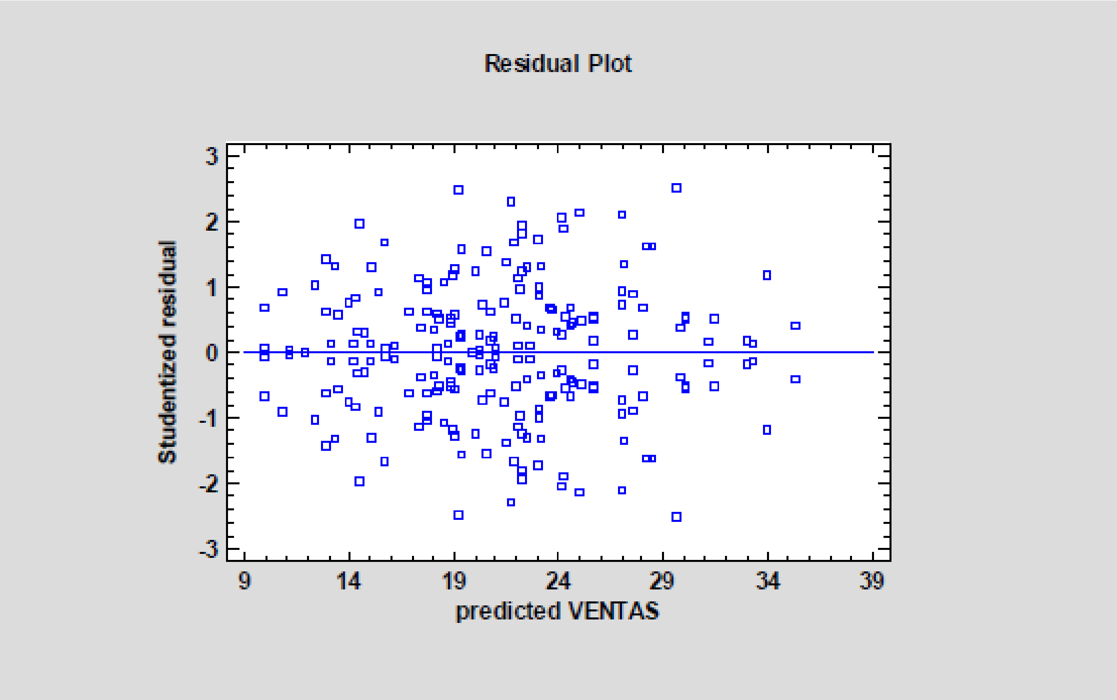


Figure 20. Plot of residuals vs. predicted values.

In the case of the example in the figure, it is observed that there are no residuals exceeding the ±3 bands, therefore no outliers are considered to be present.

Another common formal procedure in experiments where the variance is analysed is to use the normal probability plot, as shown in Figure 21, to detect any residual whose value is much higher than the others [60].

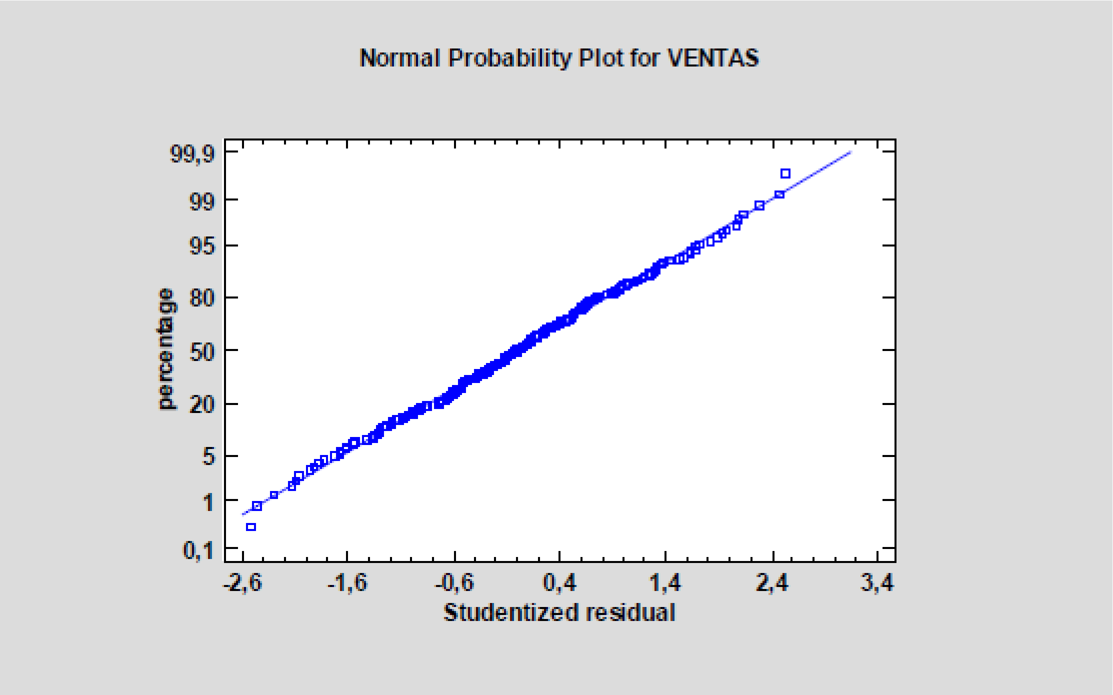


Figure 21. Normal probability plot.

In the case of the example in figure 21, it can be seen that there are no values of residuals that are much higher than the others, and there are no anomalies. Therefore, it is considered that there are no outliers present in this plot either.

Another formal procedure for the detection of outliers is the use of Box and Whisker Plots, as shown in Figure 22, as they allow a simple detection of unusual values that are outside the range of their quartiles. The quartiles used by the diagram are equal divisions of the data every ¼ as the name indicates [60]. The inconvenience of this methodology is that it does not take into account the dependence between the two main factors to be analysed: primary energy and floor area, because as already observed above, the first factor depends on the second as it is given in units of kWh/m^2*year, making it difficult to differentiate between a building with a high floor area, and therefore a high qualification, or an atypical value.

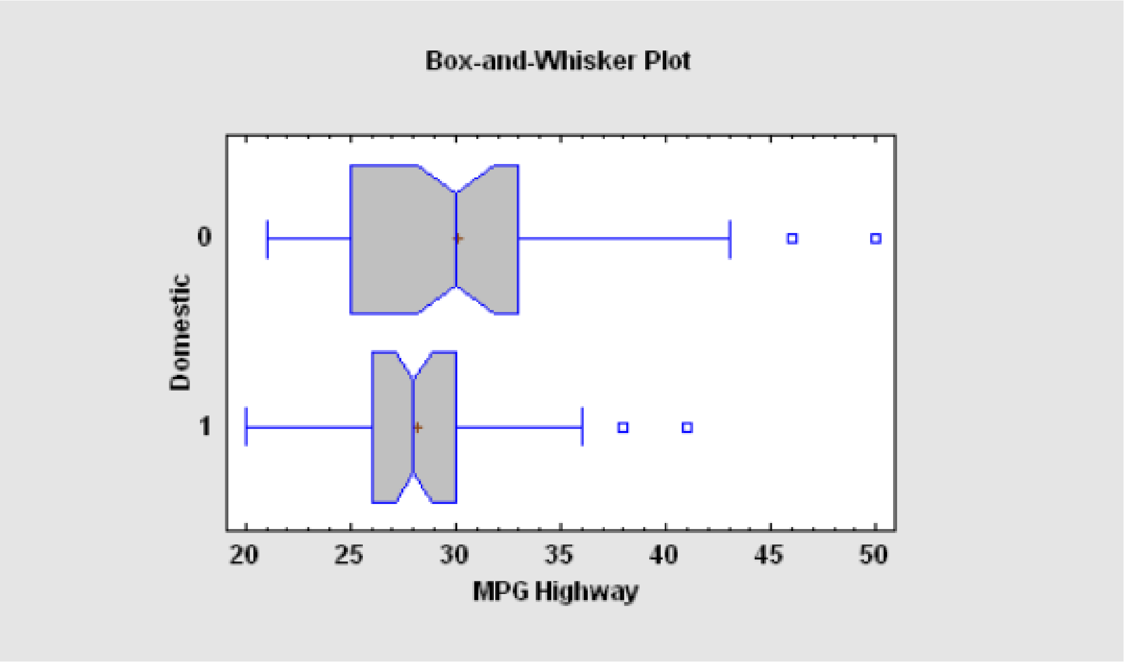


Figure 22. Box and Whiskers Plot.

In the case of the example in the figure, it can be seen that there are values out of the whiskers so these observations must be treated as outliers.

Finally, the last procedure for the detection and control of outliers is performed by X-Y Plot visualisation where both factors [48], Y primary energy and X floor area, are compared.

In this simpler way than the previous ones, a quick visualisation of the set can be obtained for the subsequent exclusion of outliers. In this case, outliers would be considered as tiny or extremely exaggerated areas that may interfere with the construction of an archetypal building for its class. EPC certifications with negative primary energy as the target is nearly zero emissions (emissions below zero as negative EPC means that the office has a lot of renewable energy installed, so it is not strictly an outlier but has to be considered separately). Furthermore, correlations between the two factors that result in very high primary energy values and very high surface areas or the opposite would be treated as outliers, as this would be the opposite of their natural relationship between EPC rating value and floor area. Ultimately, any ratings that are already zero-emission should also be excluded, as they are not relevant data for the purpose of this dissertation.

The proposed methodology will be applied in the next chapter together with the simulations and the presentation of the results plus recommendations.

3.2.2 CLASSIFICATION OF BUILDING CLASSIFICATION

The methodology employed in this dissertation begins with the formation of the clusters seen previously according to the floor area variable. Secondly, the data will be reviewed to identify outliers by applying simple regression statistical techniques between the variables x and y (floor area and primary energy, respectively), complementing the study with the analysis of the residuals plot, probability plot, ANOVA table and plot of fitted model. The last analysis will allow to detect outliers easily and in a very visual way while also facilitating the verification of the simple regression as significant or not.

All statistical tests will be carried out with the help of Statgraphics-19 x64 software [61], as it is an intuitive application to use while providing statistically relevant results. Moreover, it is the software used to carry out the exercises and examples in the globally referenced book on statistics and design of experiments, Montgomery [60].

Subsequently, after refining the observations, the histogram model will be applied to intuitively visualise which clusters are energy efficient and which clusters need measures to enhance their energy efficiency and to add percentages of each energy rating in order to know the real state of the EPCs.

First, the complete histogram of all samples will be made without differentiating by clusters, which will allow us to have an overall view of how many EPCs of each type exist and how they are distributed among the respective energy ratings. After analysing the whole, the clusters will be analysed individually.

In case a cluster is energy efficient, i.e. the percentage of A-rated EPCs is 95% or higher (for a maximum of 5% of non-energetically efficient EPCs), it will be noted and the next cluster will be analysed.

In case a cluster is not energy efficient, the average of the energy ratings of the data within the cluster will be calculated taking into account the percentages of the histogram with the aim of proposing a reference building on which actions can subsequently be implemented to improve the energy efficiency of the group as far as possible.

Before the simulation starts, a reference building for each cluster must be developed using Statgraphics software to statistically analyze the offices in each group. By applying statistical cluster analysis techniques, the average floor area and primary energy will be obtained as results and assigned as reference parameters.

Then, using the SBEM-mt software, different combinations of measures on the reference building of each group will be carried out. The results will be subsequently analyzed in Excel, as this tool allows us to directly copy the data from the software to its sheets, facilitating the transfer of information.

During the simulations, the parameters of the standard office are varied, and this will allow us to determine which measures are more or less effective. The parameters to be considered may be categorized into three groups, as shown in Table 13:

Table 13. . Parameters of energy efficiency measures to model in SBEM-mt software.

Building envelope measures	Wall U-value
	Glass U-value
	Glass shading
	Floor insulation
	Roof insulation (where relevant)
Building energy systems measures	Domestic hot water
	Air conditioners
Renewable energy measures	Photovoltaic systems

Figure 23 shows the flow chart of the methodology to be implemented in this dissertation.

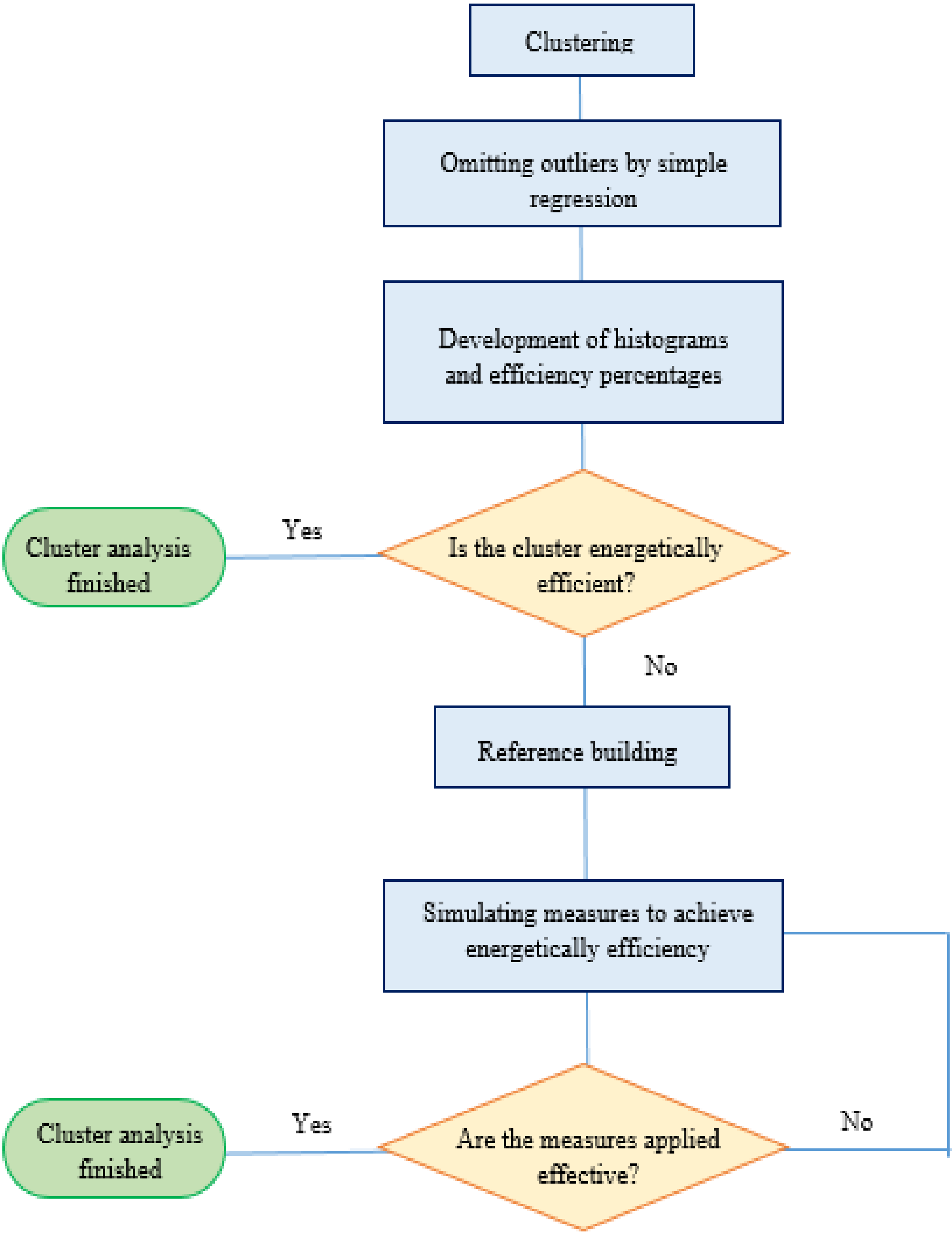


Figure 23. Methodology flow chart.

CHAPTER 4: ANALYSIS AND DISCUSSION OF THE ACHIEVED RESULTS

4.1 ACHIEVED RESULTS

4.1.1 RESULTS FOR ASSET RATING CLUSTERS

4.1.1.1 RESULTS FOR ASSET RATING CLUSTER O1

To start with, as shown in Figure 24, a simple regression is performed to observe the influence of the "floor area" variable, or x-axis, on the "primary energy" variable of the offices, or y-axis.

This statistical analysis is performed for the first cluster Asset Rating and floor area from 1 m^2 to 250 m^2 (cluster called Asset Rating O1).

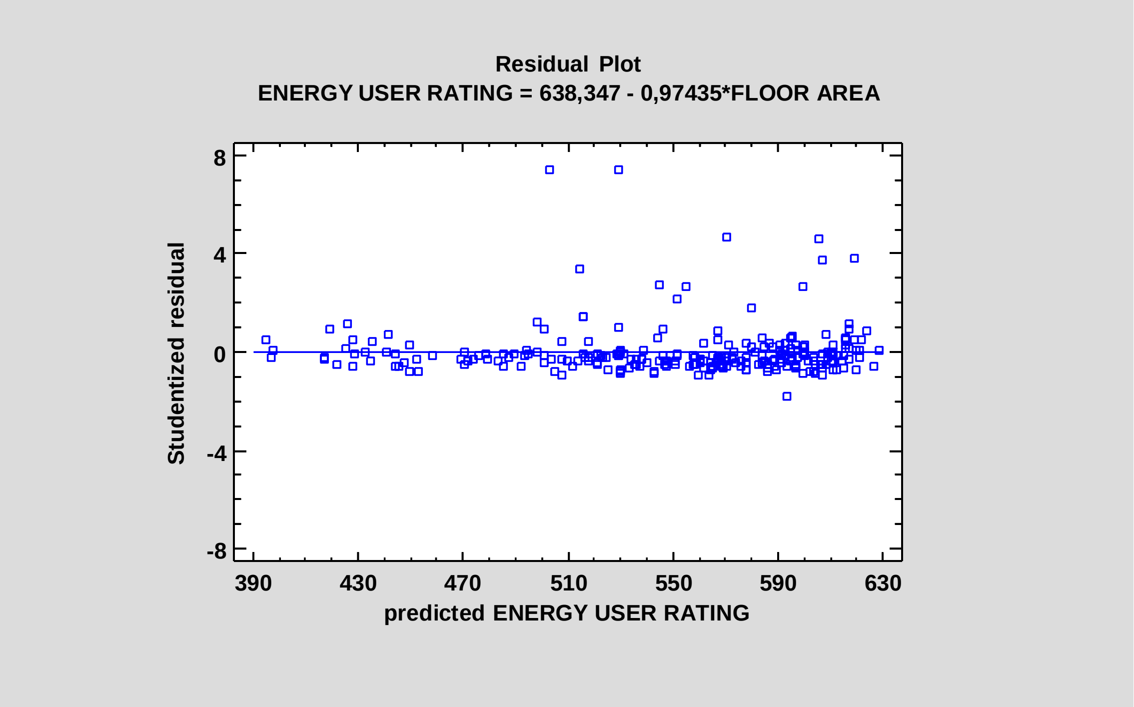


Figure 24. Plot of Residuals vs Predicted for cluster O1 Asset Rating.

The plot of studentized residuals vs floor area in Figure 25 shows how the observations are located in the form of a band around the zero value. First, for the statistical analysis we have to treat the data so that points outside the bands [-2, 2] and [-3, 3] will be removed as they are outliers that impair the regression results.

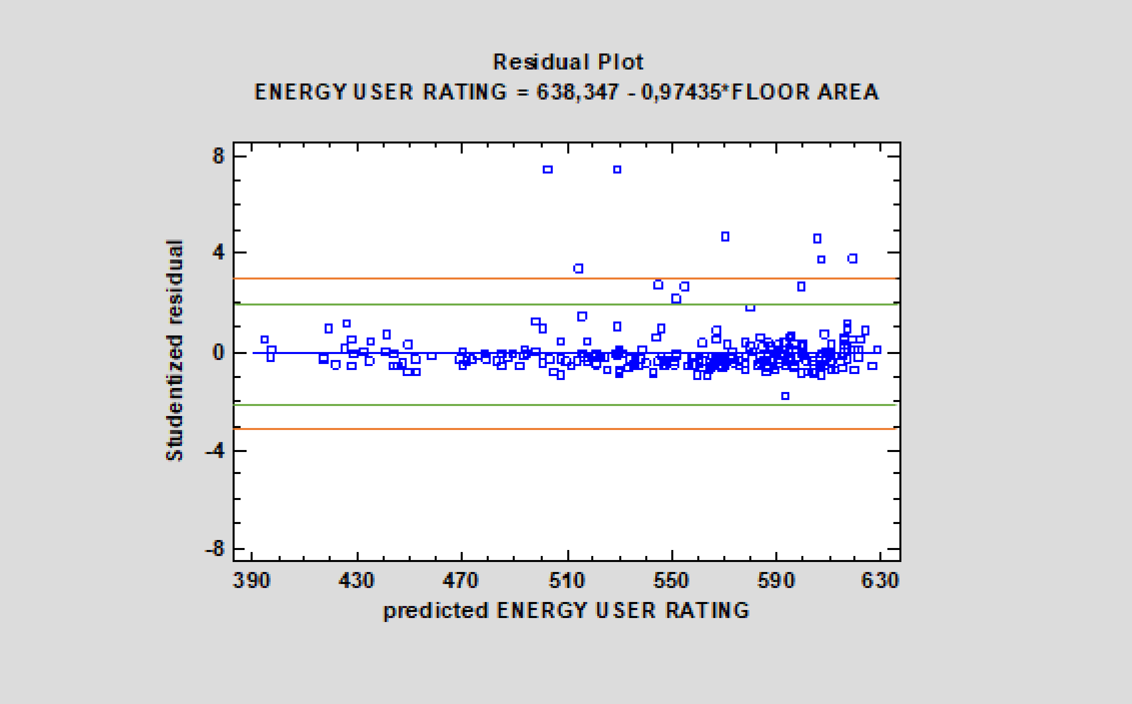


Figure 25. Plot of Residuals vs Predicted for cluster O1 Asset Rating with outlier's delimitation bands.

A total of 11 observations were removed, Figure 26 shows the new simple regression obtained:

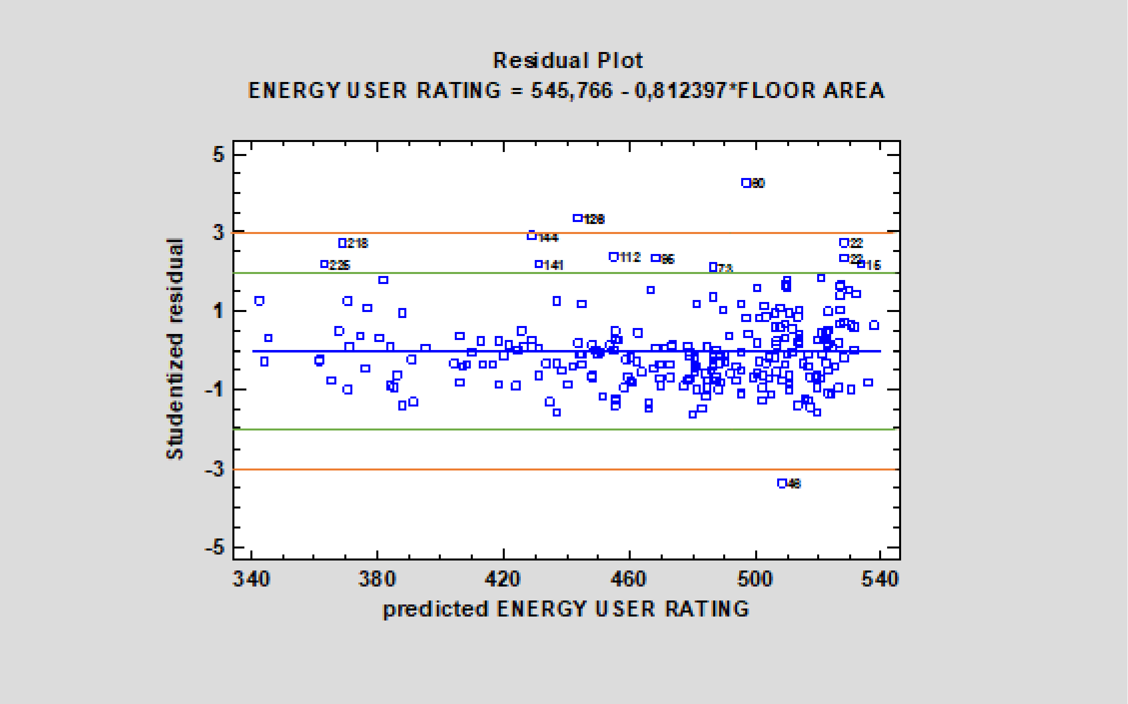


Figure 26. Outliers from Plot of Residuals vs Predicted for cluster O1 Asset Rating.

The outlier elimination process is an iterative process, meaning that each time an outlier is eliminated, the plot is readjusted (keeping the outliers previously present, because outliers cannot become not outliers) and may show new outliers that were previously not clearly visible.

Finally, Figure 27 shows the result obtained as the final regression plot, constructed by a total of 178 non-outlier observations.

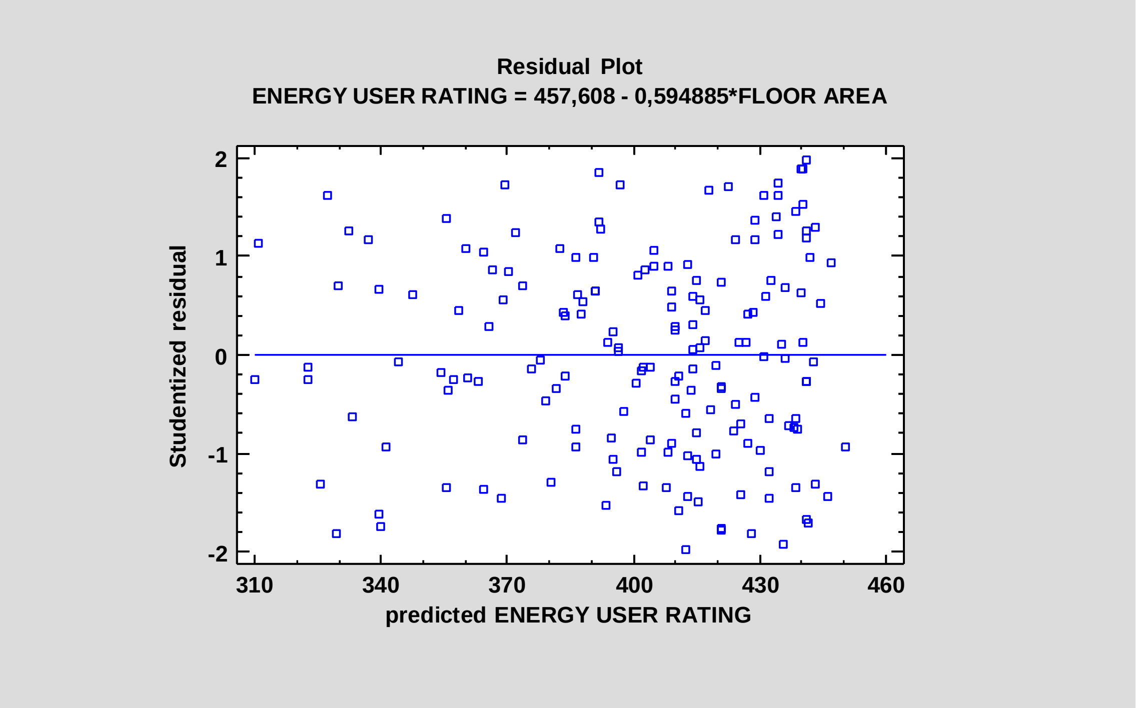


Figure 27. Final Plot of Residuals vs Predicted for cluster O1 Asset Rating.

The normality plot could also be analysed to observe any other problems present in the data, as the normality hypothesis but this is not important to this dissertation part. As shown in Figure 28, there is no problem with normality (the slightly deviated tails are not significant enough to determine any problem with the variance of the model), but the important thing is that there are no more outliers in the model.

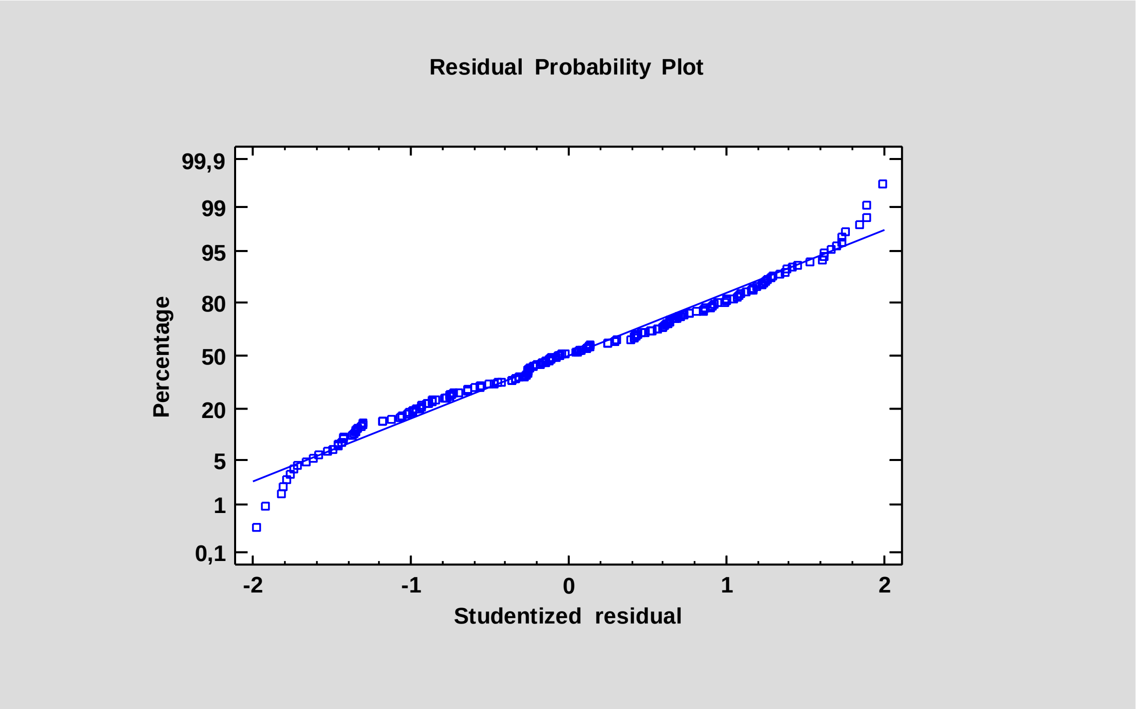


Figure 28. Residual Probability Plot for cluster O1 Asset Rating.

In the following, the clarification shown below is proposed for all regression plots of fitted models:

- The points marked with red crosses are outliers that do not fit the model proposed for the regression and therefore exceed the limits proposed in the residual plots.
- Points marked with blue squares are acceptable observations that continue to fit the model.
- The green lines are the acceptance bands of the regression model.

Finally, Figure 29 shows the final regression for the asset design type rating offices O1 within the interval [1 - 250] m^2 after removing the outliers outside the bands. Although the slope of the line does not vary much, it is observed that the value of primary energy decreases as the floor area increases.

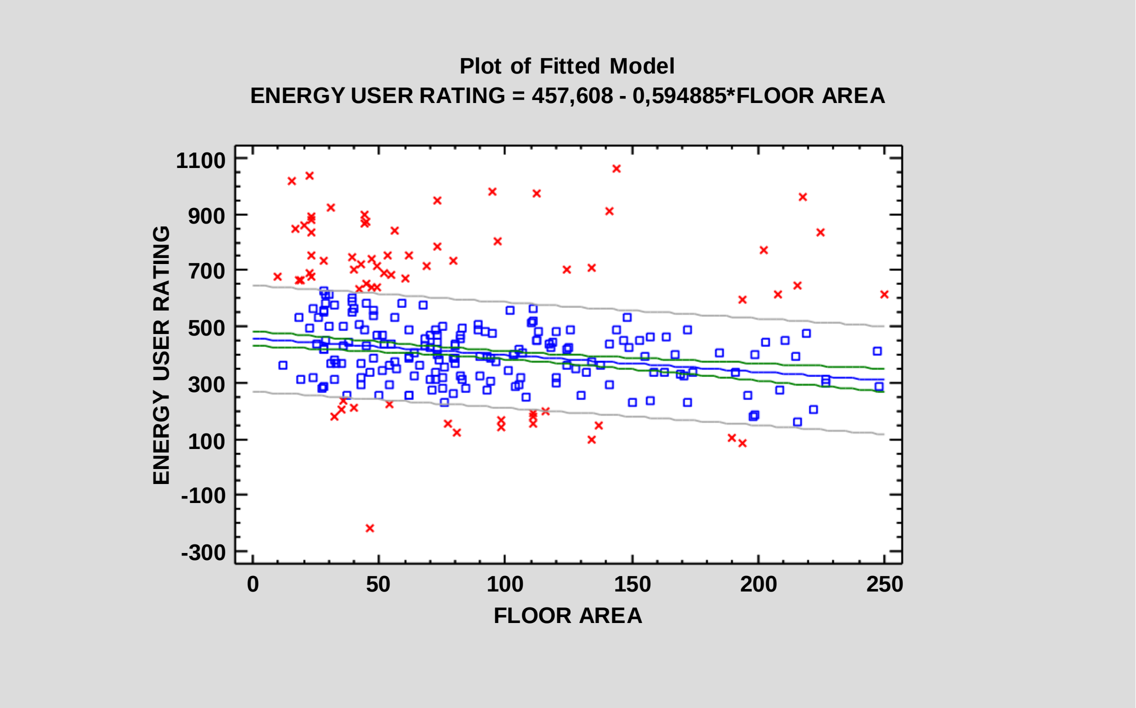


Figure 29. Dispersion graph for cluster O1 Asset Rating.

From now until the end of this part, the methodology carried out previously is maintained to analyse the data of the asset classification clusters (as well as the design rating clusters) O1 (carried out previously) to O4. The following cluster analyses will be presented as follows:

1. Figures resulting from the omission of outliers by linear regression: plot of residuals vs predicted and residual probability plot.
2. Figure of dispersion graph.
3. Table of representative building characteristics.

4.1.1.2 RESULTS FOR ASSERT RATING CLUSTER O2

This second statistical analysis is performed for the second cluster Asset Rating and floor area from 251 m^2 to 500 m^2 (cluster called Asset Rating O2), results are shown below in Figure 30.

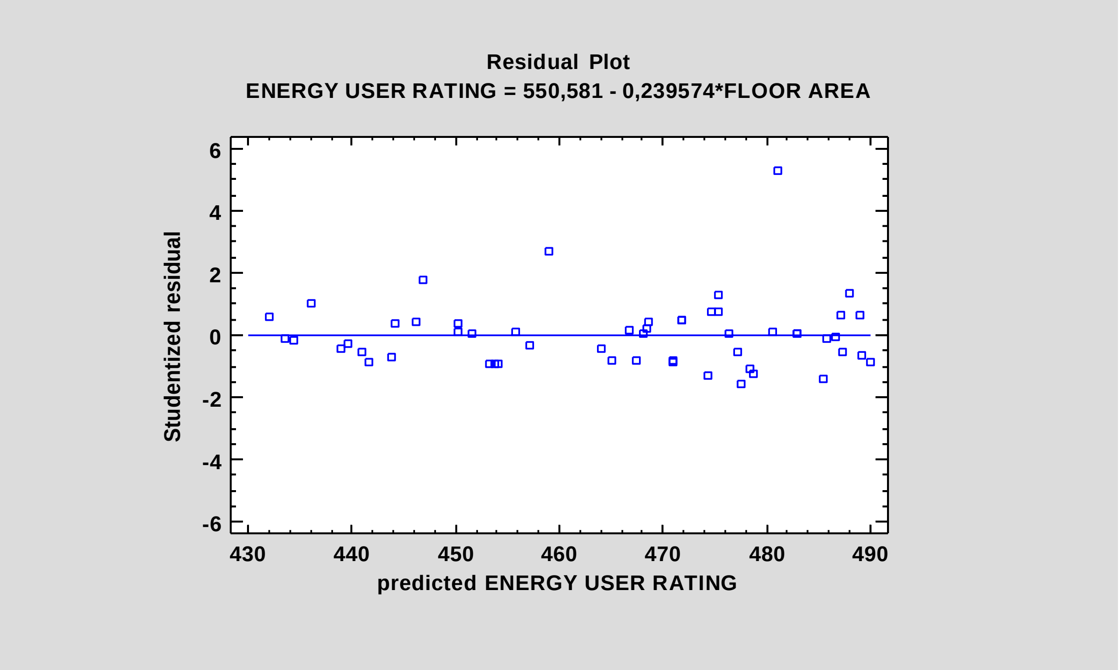


Figure 30. Plot of Residuals vs Predicted for cluster O2 Asset Rating.

Finally, Figure 31 shows the result obtained as the final regression plot, constructed by a total of 48 non-outlier observations. A total of 16 observations were removed.

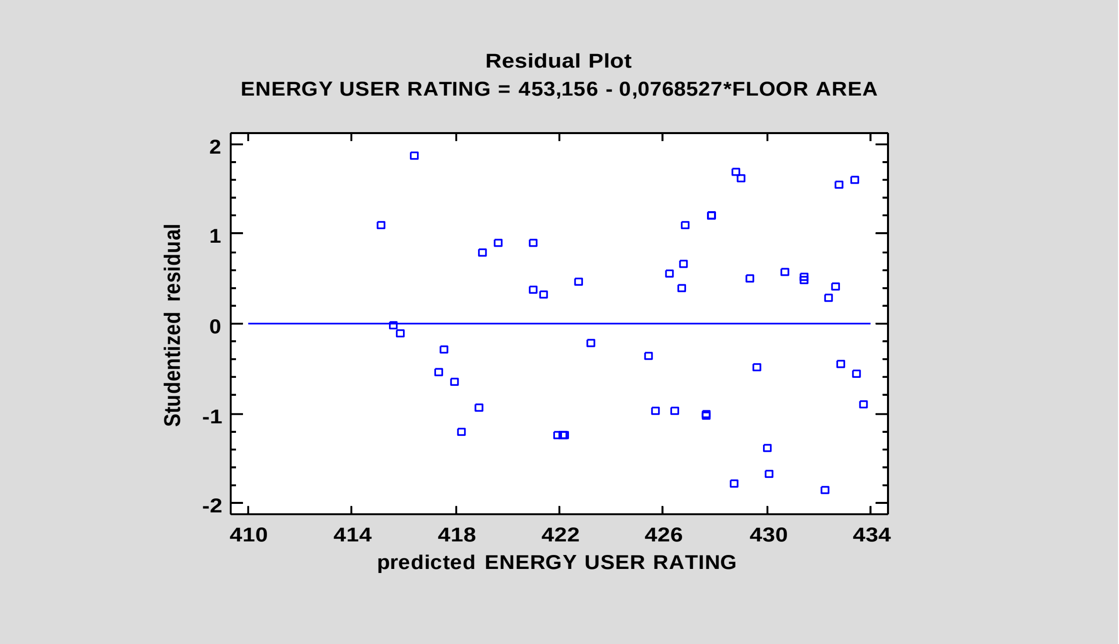


Figure 31. Final Plot of Residuals vs Predicted for cluster O2 Asset Rating.

As shown in Figure 32, there are no more outliers in the model.

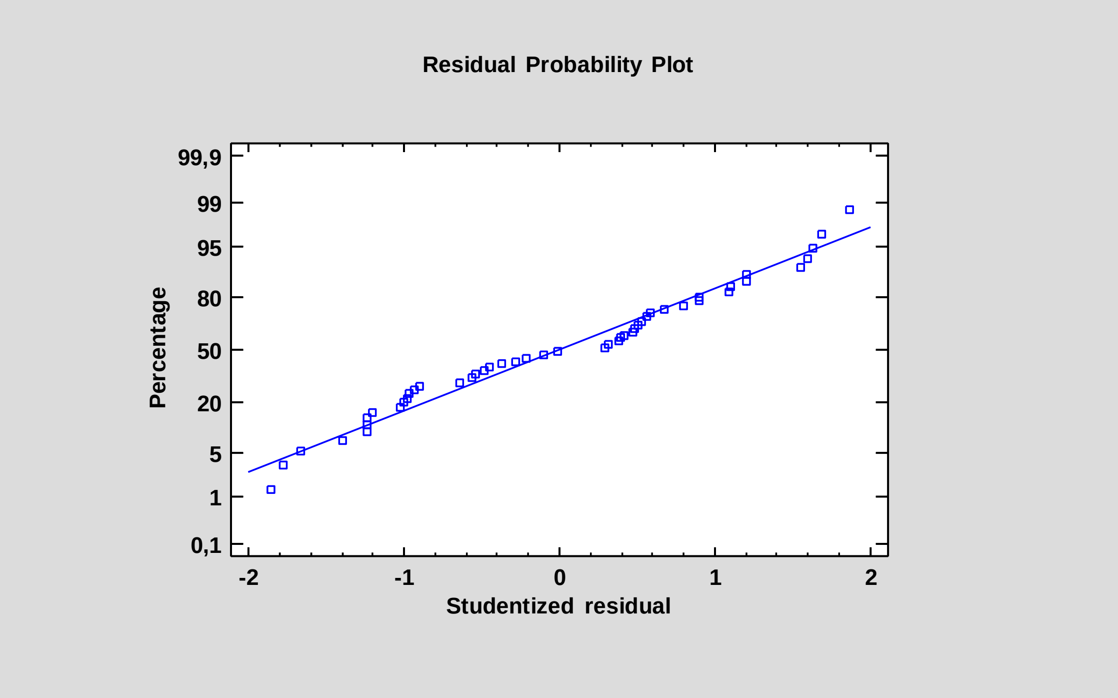


Figure 32. Residual Probability Plot for cluster O2 Asset Rating.

Finally, Figure 33 shows the final regression for the asset design type rating offices within the interval [251 – 500] m2 after removing the outliers outside the bands. Although the slope is not very steep, it is appreciated that primary energy value decreases as the floor area increases.

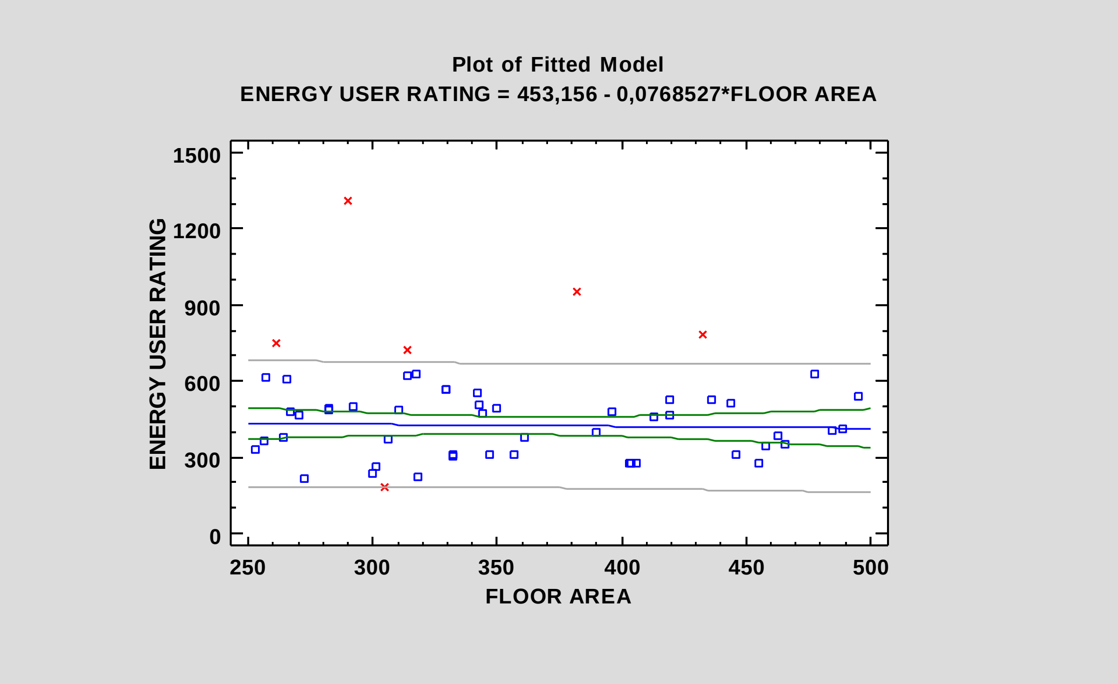


Figure 33. Dispersion graph for cluster O2 Asset Rating.

4.1.1.3 RESULTS FOR ASSERT RATING CLUSTER O3

This third statistical analysis is performed for the third Asset Rating cluster whose floor area band takes from 501 m^2 to 1500 m^2 (cluster called Asset Rating O3). Results are shown below in Figures 34, 35, 36, 37.

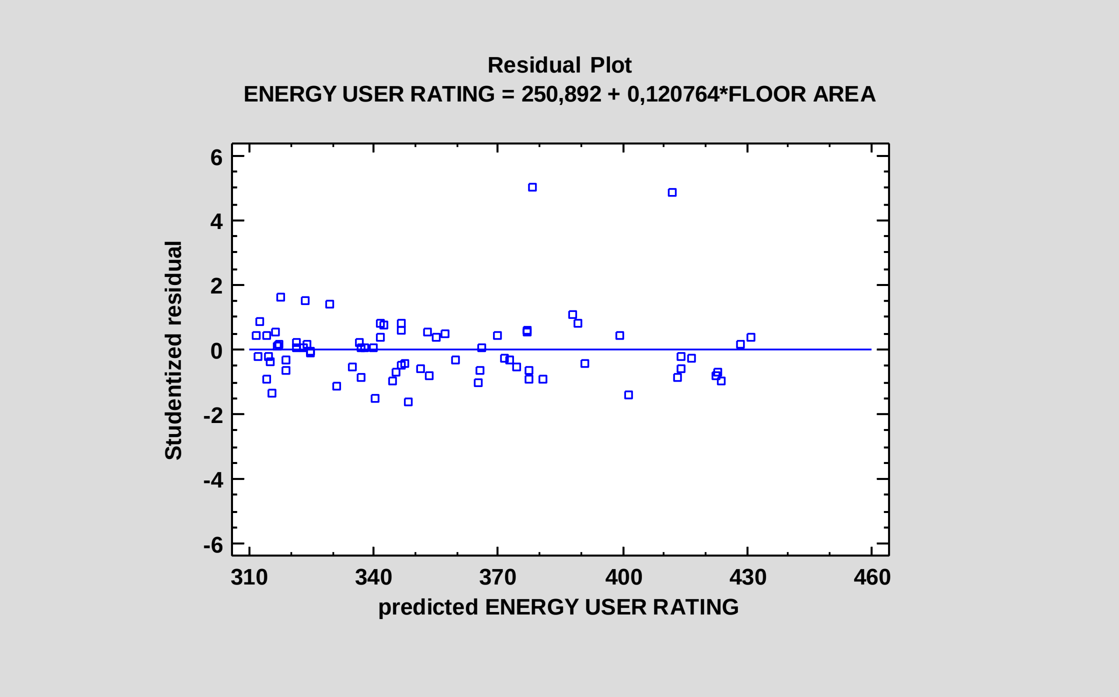


Figure 34. Plot of Residuals vs Predicted for cluster O3 Asset Rating.

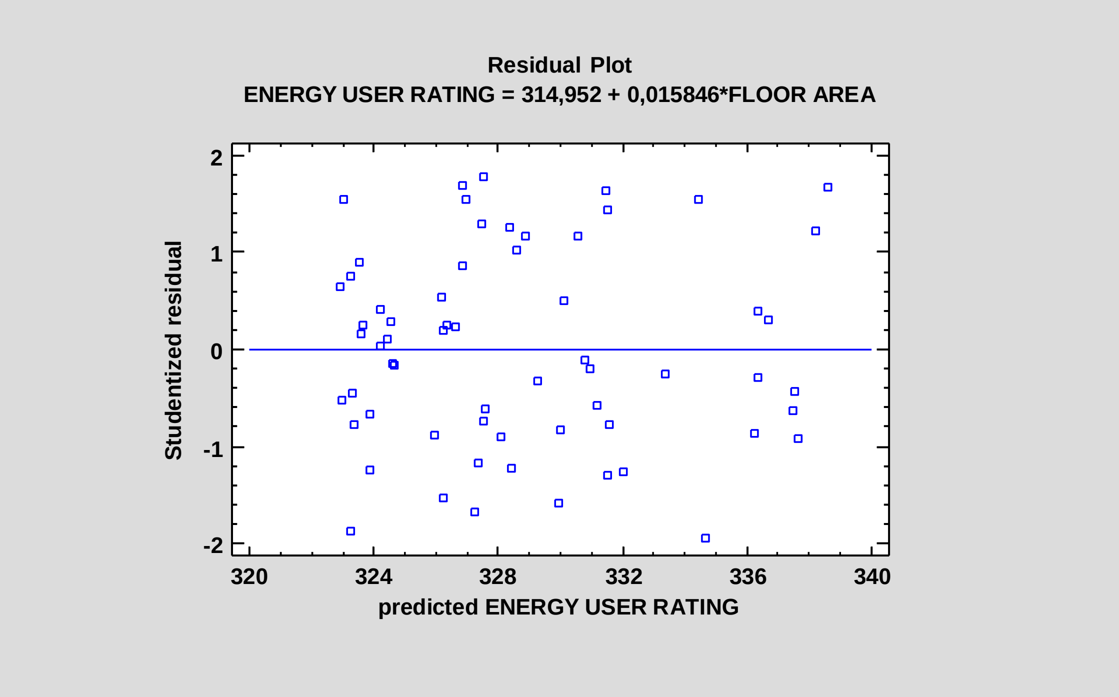


Figure 35. Final Plot of Residuals vs Predicted for cluster O3 Asset Rating.

As shown in Figure 36, there is no more outliers in the model.

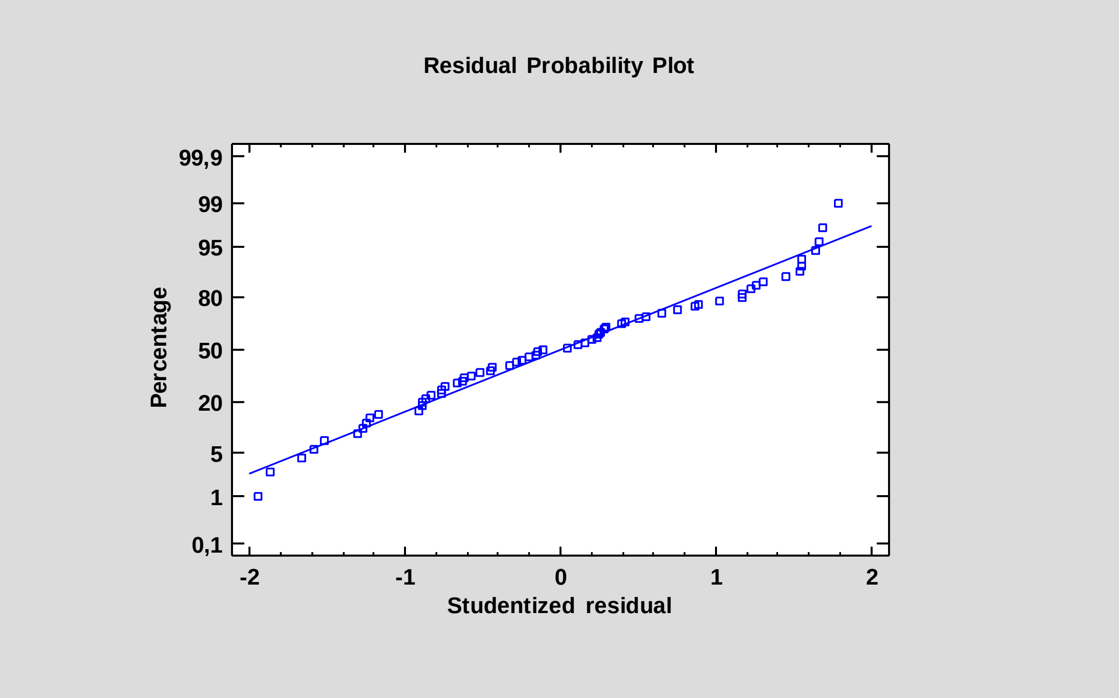


Figure 36. Residual Probability Plot for cluster O3 Asset Rating.

Finally, Figure 37 shows the final regression for the asset design type rating offices within the interval [501 – 1500] m^2 after removing the outliers outside the bands.

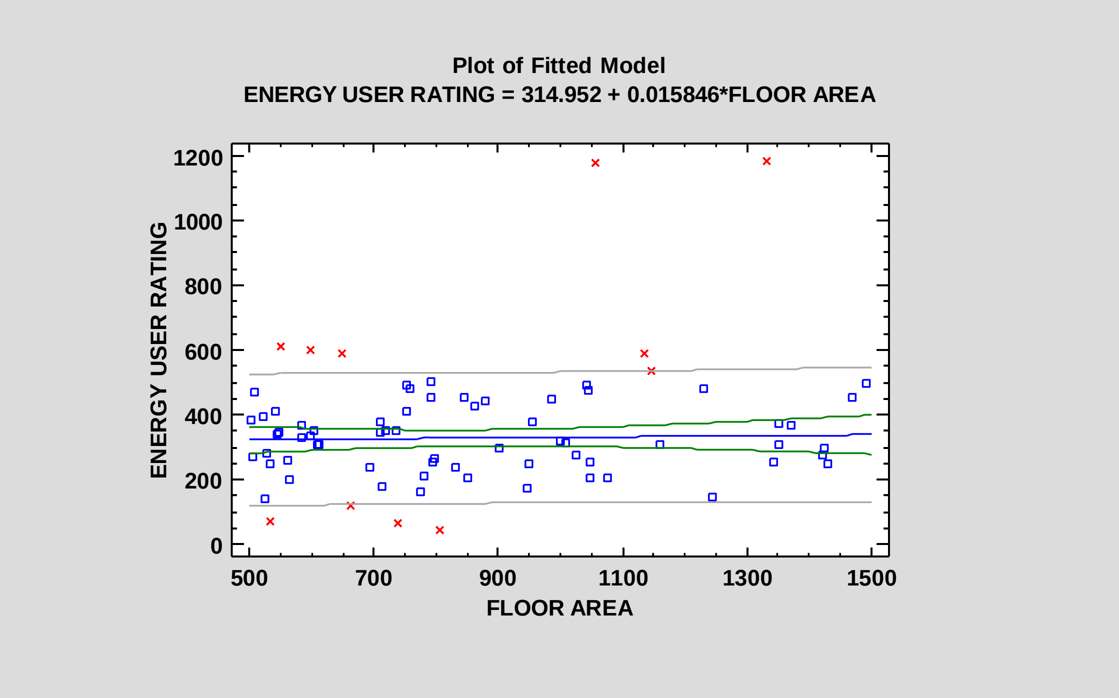


Figure 37. Dispersion graph for cluster O3 Asset Rating.

4.1.1.4 RESULTS FOR ASSERT RATING CLUSTER O4

This fourth statistical analysis is performed for the fourth Asset Rating cluster floor area from 1501 m^2 (cluster called Asset Rating O4), results are shown below in Figures 38, 39, 40, 41.

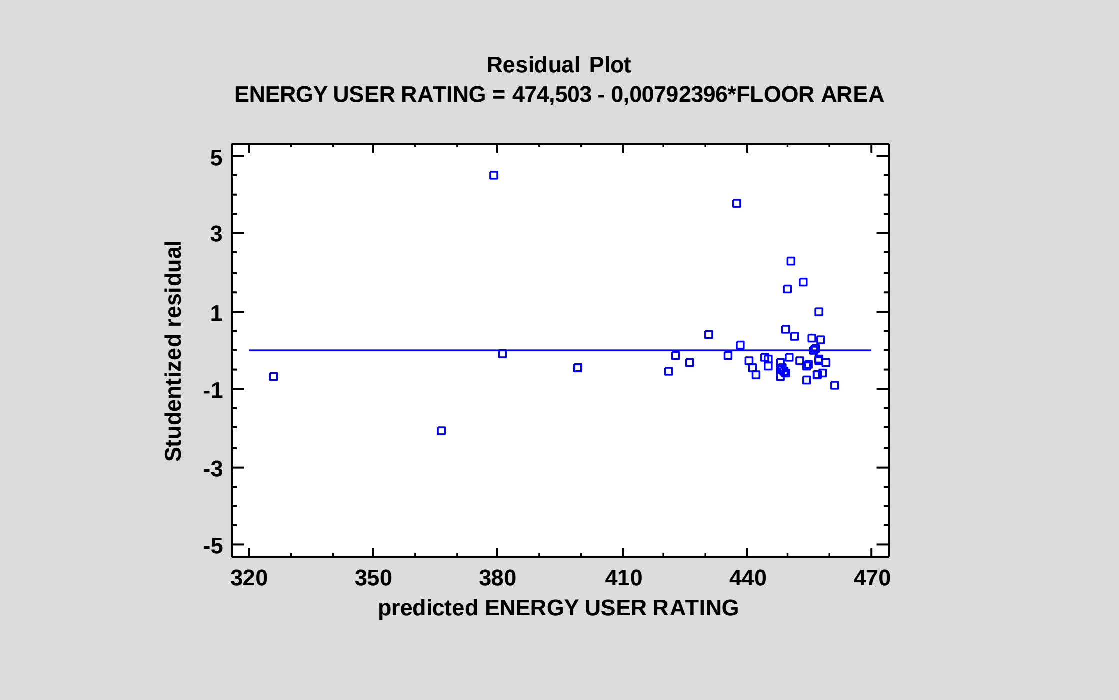


Figure 38. Plot of Residuals vs Predicted for cluster O4 Asset Rating.

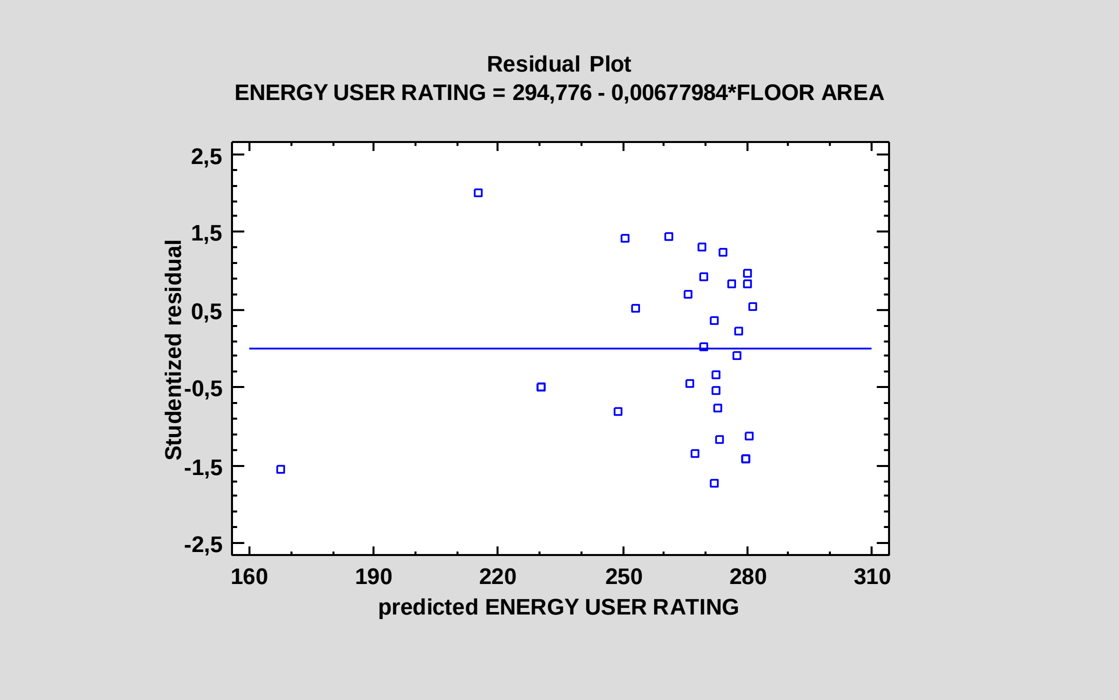


Figure 39. Final Plot of Residuals vs Predicted for cluster O4 Asset Rating.

As shown in Figure 40, there is no more outliers in the model.

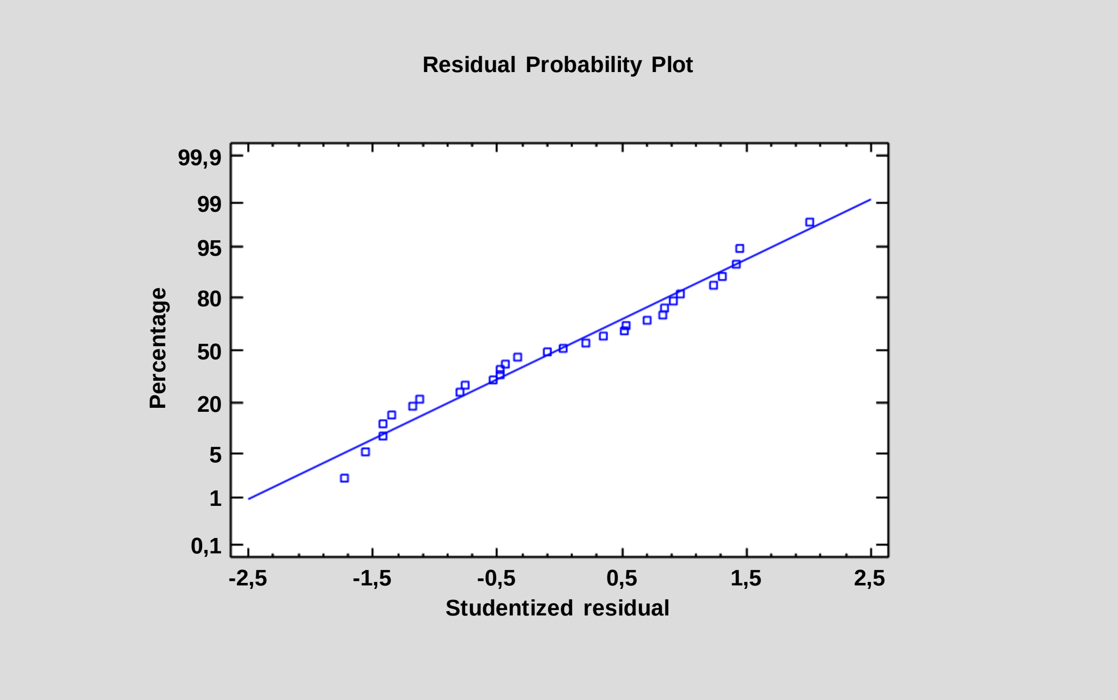


Figure 40. Residual Probability Plot for cluster O4 Asset Rating.

Finally, Figure 41 shows the final regression for the asset design type rating offices within the interval [1500+] m^2 after removing the outliers outside the bands.

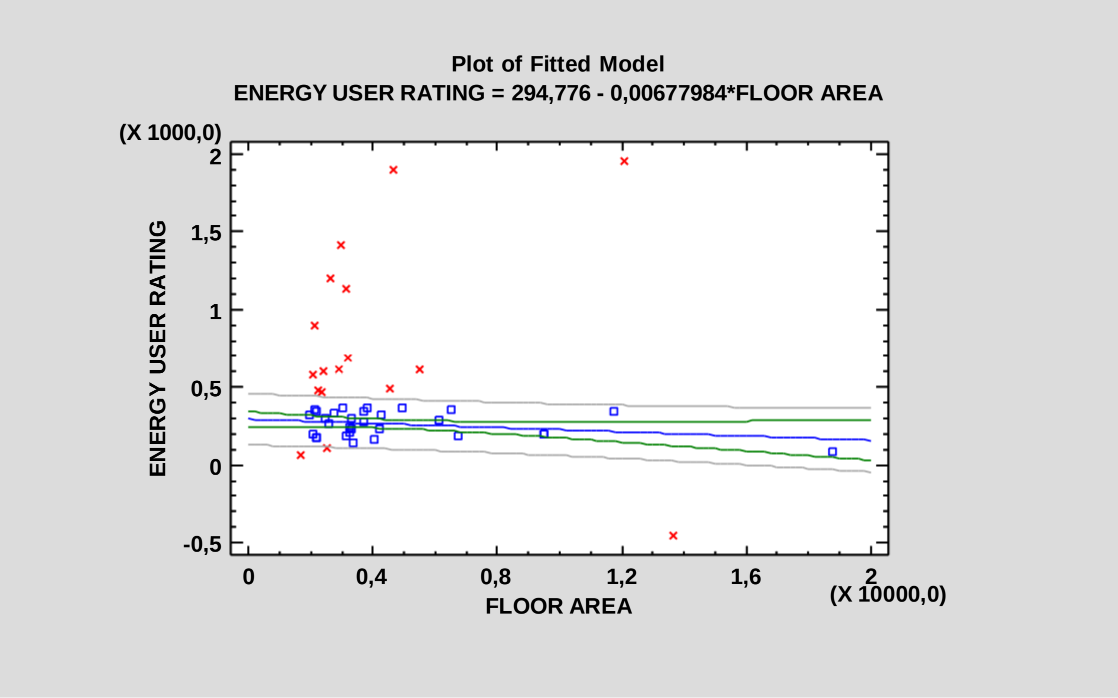


Figure 41. Dispersion graph for cluster O4 Asset Rating.

4.1.2 ENERGY RATINGS FOR ASSET RATING CLUSTERS

First of all, it will be studied if the total office stock provided by the database is energy efficient or not, as shown in Figure 42, then it will be studied for each of the four clusters (O1, O2, O3, O4) created according to the Floor Area:

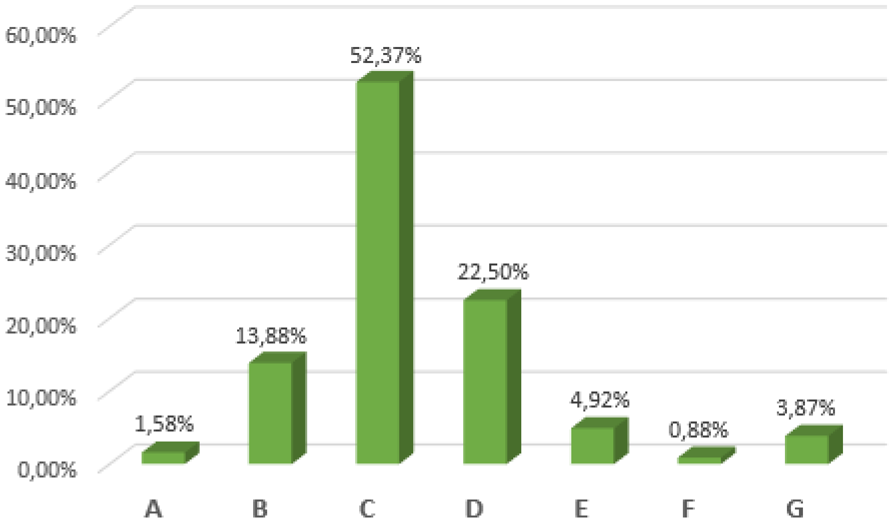


Figure 42. Energy efficiency histogram of the total office stock (asset and design rating).

At first instance, it can be seen how most of the levels of the EPC certifications are between C and D grades, which is not overly efficient but not bad results. What can be interpreted from this histogram is that a large part of the offices are at medium efficiency levels with a higher tendency to be efficient than not. These results also indicate that, if appropriate energy improvement measures are implemented, more than half of the offices will be able to change their rating to A, or B Class. However, these data have to be studied in terms of the previously formed clusters as it is of more interest to know in which floor area ranges the offices are mainly inefficient or potentially efficient in order to implement measures accordingly.

According to the data type needed by Statgraphics software to create histograms from now to the end the EPC band is going to be numeric as shown below in Table 14.

Table 14. EPC band numeric transformation.

EPC BAND	EPC BAND NUMERIC
A, A+	1
B	2
C	3
D	4
E	5
F	6
G	7

For the first cluster (O1: asset rating), it can be seen in Figure 43 how the percentages remain similar to those of the histogram for the entire office stock, the main reason for this is that most of the offices in the stock belong to this cluster.

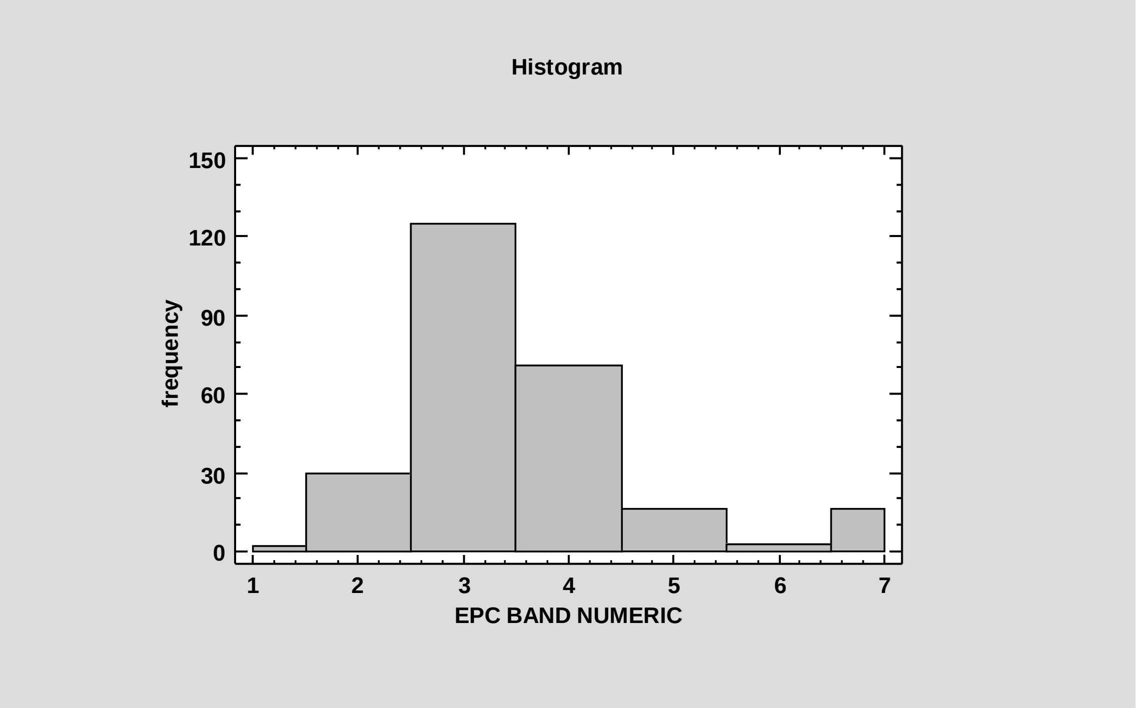


Figure 43. EPC BAND Histogram for cluster O1 Asset Rating.

In Table 15 it is seen the relative frequency of each EPC band classification.

Table 15. Frequency Tabulation for O1 Offices EPC Band

Value=EPC BAND	***Frequency***	***Relative Frequency***	***Cumulative Frequency***	***Cum. Rel. Frequency***
1=A, A+	2	0.01	2	0.01
2=B	30	0.11	32	0.12
3=C	125	0.48	157	0.60
4=D	71	0.27	228	0.87
5=E	16	0.06	244	0.93
6=F	3	0.01	247	0.94
7=G	16	0.06	263	1.00

In the following, Figures 44 and 45 show how clusters O2 and O3 take on a similar silhouette to the histogram presented above. The main difference of Cluster O2 lies in the non-existence of A-rated (efficient) EPCs while those of Cluster O3 focus on the opposite. In the histogram of the third cluster, it can be seen how there are no EPCs that present a serious energy inefficiency of their offices. It is a more neutral histogram with main rating in the C classification of the EPCs above the average of the total stock which indicates that with the right measures most of their offices can be placed at A or B levels of energy efficiency.

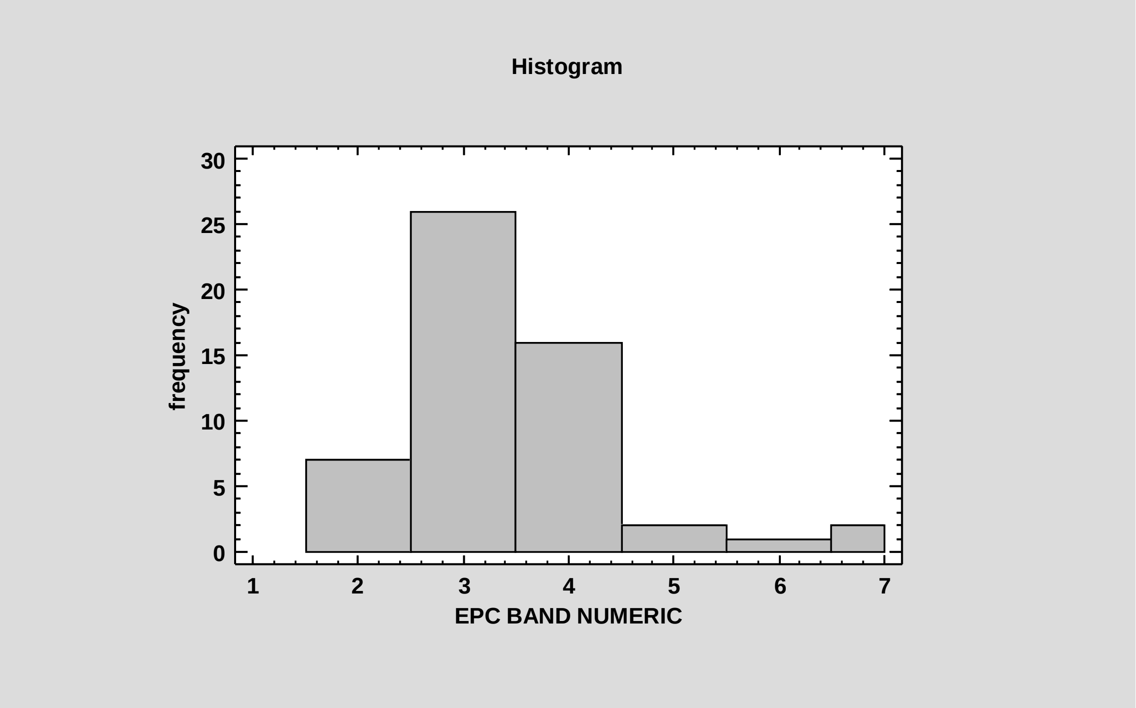


Figure 44. EPC BAND Histogram for cluster O2 Asset Rating.

In Table 16 it is seen the relative frequency of each EPC band classification.

Table 16. Frequency Tabulation for O2 Offices EPC Band

Value=EPC BAND	**Frequency**	**Relative Frequency**	**Cumulative Frequency**	**Cum. Rel. Frequency**
1=A, A+	0	0.00	0	0.00
2=B	7	0.13	7	0.13
3=C	26	0.48	33	0.61
4=D	16	0.30	49	0.91
5=E	2	0.04	51	0.94
6=F	1	0.02	52	0.96
7=G	2	0.04	54	1.00

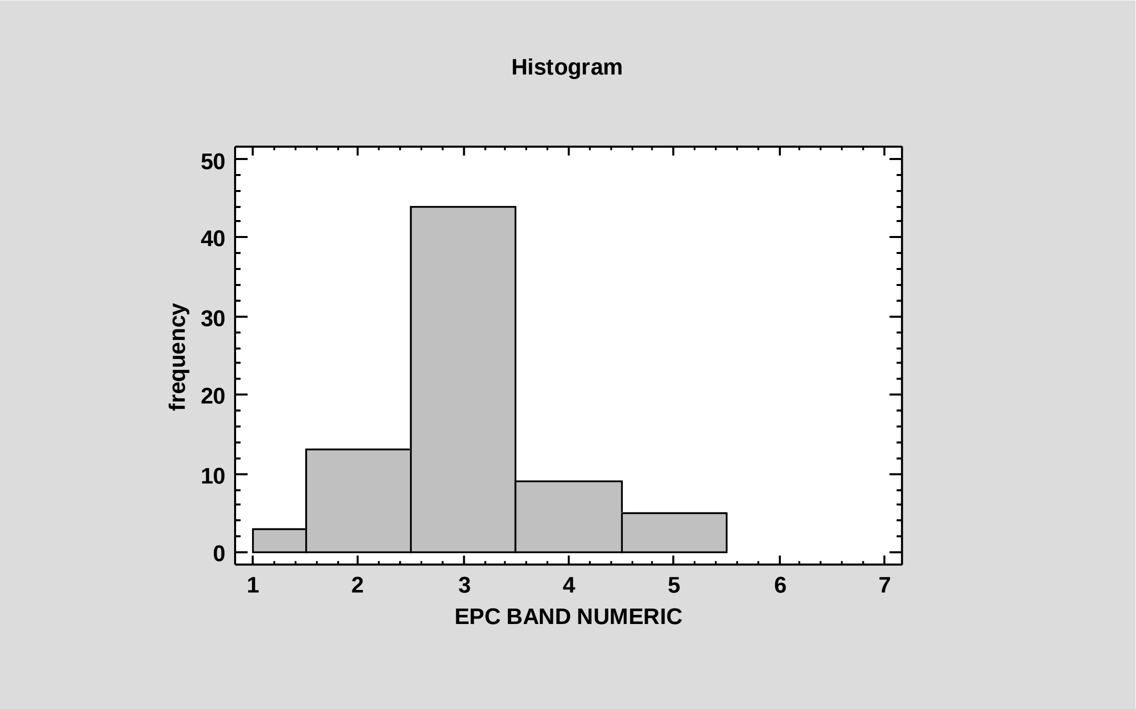


Figure 45. EPC BAND Histogram for cluster O3 Asset Rating.

In the Table 17 it is seen the relative frequency of each EPC band classification.

Table 17. Frequency Tabulation for O3 Offices EPC Band

Value=EPC BAND	***Frequency***	***Relative Frequency***	***Cumulative Frequency***	***Cum. Rel. Frequency***
1=A, A+	3	0.04	3	0.04
2=B	13	0.18	16	0.22
3=C	44	0.59	60	0.81
4=D	9	0.12	69	0.9324
5=E	5	0.07	74	1.00
6=F	0	0.00	74	1.00
7=G	0	0.00	74	1.00

Finally, Figure 46 shows cluster O4 (offices with the largest surface area). It can be seen how the shape of this last cluster does not look like the previous ones, although it maintains the predominance of offices whose energy certifications are between levels B, C and D, it also presents a high number of offices whose EPCs have G and F ratings (very inefficient).

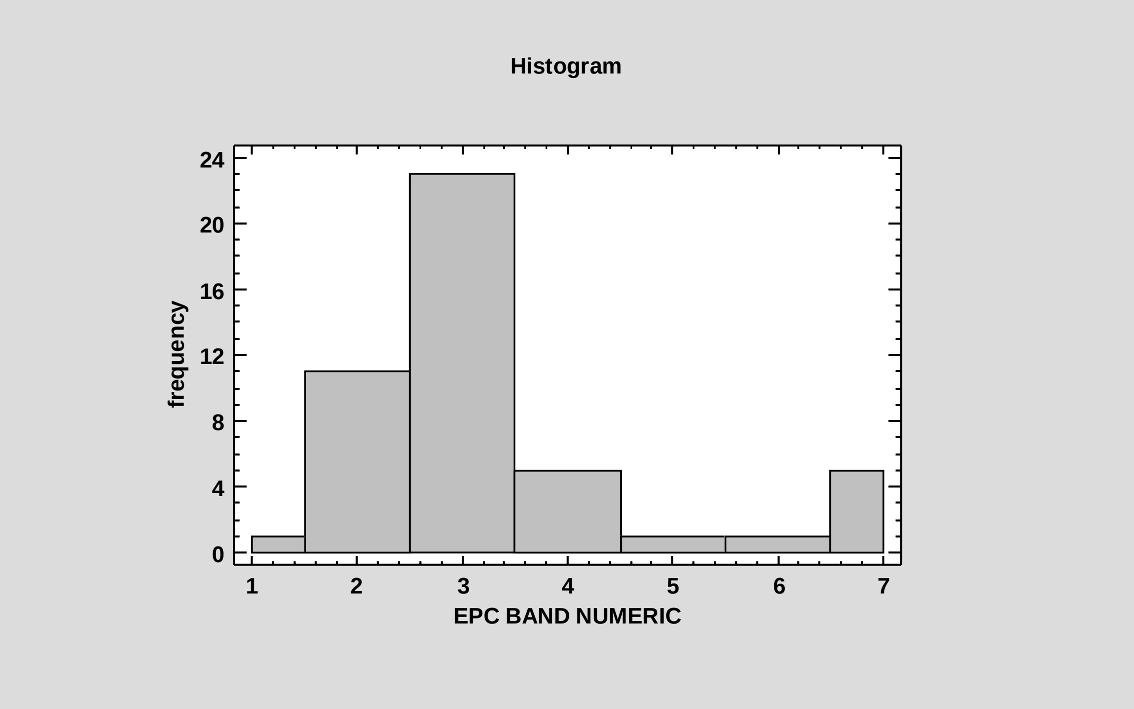


Figure 46. EPC BAND Histogram for cluster O4 Asset Rating.

In the Table 18 it is seen the relative frequency of each EPC band classification.

Table 18. Frequency Tabulation for O4 Offices EPC Band

Value= EPC BAND	***Frequency***	***Relative Frequency***	***Cumulative Frequency***	***Cum. Rel. Frequency***
1=A, A+	1	0.02	1	0.02
2=B	11	0.23	12	0.26
3=C	23	0.49	35	0.74
4=D	5	0.11	40	0.85
5=E	1	0.02	41	0.87
6=F	1	0.02	42	0.89
7=G	5	0.11	47	1.00

When one looks at Tables 15, 16, 17 and 18 (Asset Rating) and Tables 24, 25, 26 and 27 (Design Rating) it can be seen how, in general, smaller offices offer a higher percentage of worst performing EPC ratings (letters E, F and G). It is due to the fact that smaller offices tend to be older than larger ones as historically office construction in Malta was based on small buildings. Therefore, it is recommended to pay more attention to smaller floor area offices for the energy renovation of buildings.

4.1.3 REFERENCE BUILDINGS FOR ASSET RATING CLUSTERS

The representative building in this category is simple to define at least in terms of floor area. It is assigned an average value and then the primary energy value is calculated. The results presented below in Table 19, Table 20, Table 21 and Table 22 have been obtained by performing a one-way ANOVA statistical analysis.

From the statistical results for each group, the database was checked to identify an actual office certificate that had similar floor area parameters to the one obtained. The original assessor was contacted to provide the appropriate file that has the entire building database, such as zoning, building material, wall and roof characteristics, building energy system characteristics, etc., to be used as the input reference file for that office category.

Table 19. Representative building parameters for cluster O1 Asset Rating.

Primary energy	537.1 kWh/ m^2*year
Floor Area	104.128 m^2
EPC Band	D

Table 20. Representative building parameters for cluster O2 Asset Rating.

Primary energy	460.949 kWh/ m^2*year
Floor Area	358.490 m^2
EPC Band	C

Table 21. Representative building parameters for cluster O3 Asset Rating.

Primary energy	326.167 kWh/ m^2*year
Floor Area	864.239 m^2
EPC Band	C

Table 22. Representative building parameters for cluster O4 Asset Rating.

Primary energy	317.981 kWh/ m^2*year
Floor Area	4451.432 m^2
EPC Band	C

The next step is to use the same methodology applied previously to analyse the clusters that belong to the second category of offices, design rating or offices that have not been built yet.

4.1.4 RESULTS FOR DESIGN RATING CLUSTERS

4.1.4.1 RESULTS FOR DESIGN RATING CLUSTER O1

To start with, as shown in Figure 47, a simple regression is performed to observe the influence of the "floor area" variable, or x-axis, on the "primary energy" variable of the offices, or y-axis.

This statistical analysis is performed for the first cluster Design Rating and floor area from 1 m^2 to 250 m^2 (cluster called Design Rating O1).

Outliers (at the first view) are labelled.

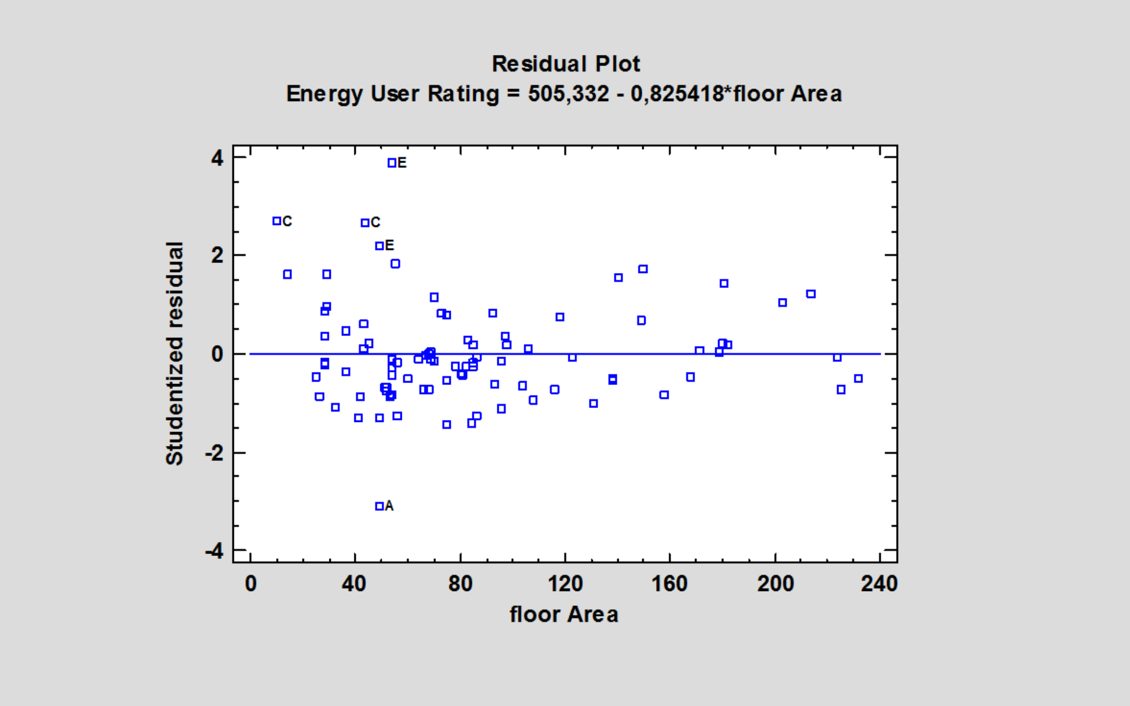


Figure 47. Plot of Residuals vs Predicted for cluster O1 Design Rating.

Figure 48 shows the residual plot after removing the outliers.

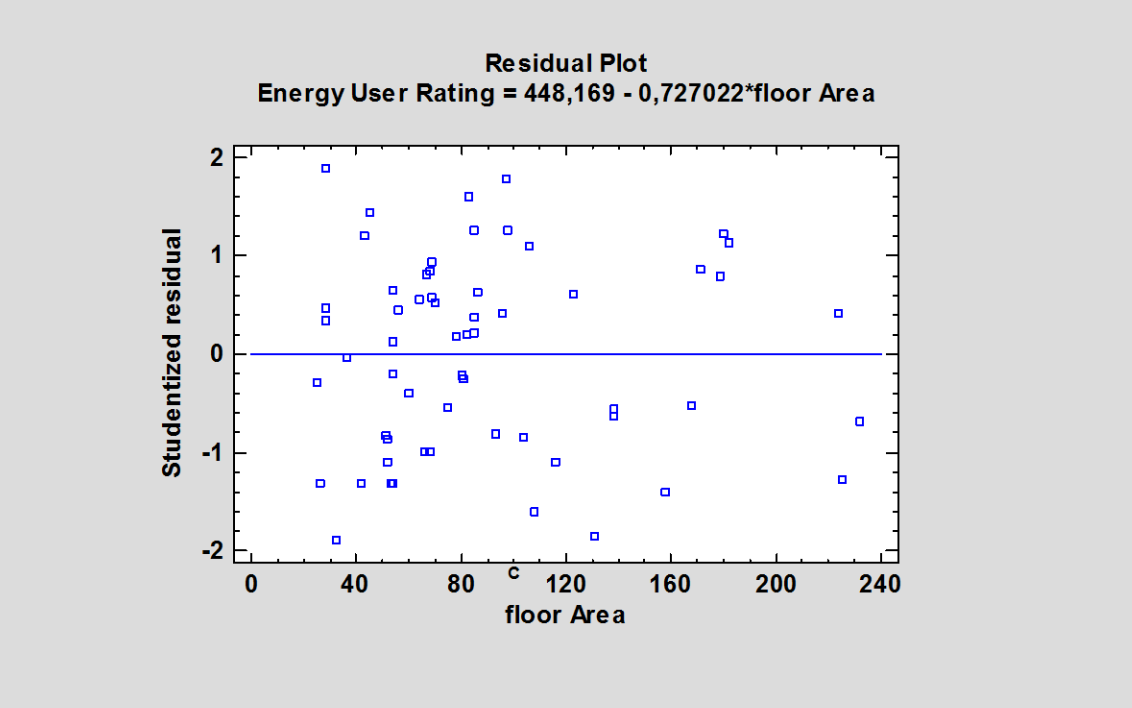


Figure 48. Final Plot of Residuals vs Predicted for cluster O1 Design Rating.

As shown in Figure 49, it is proved that there are no more outliers in the model.

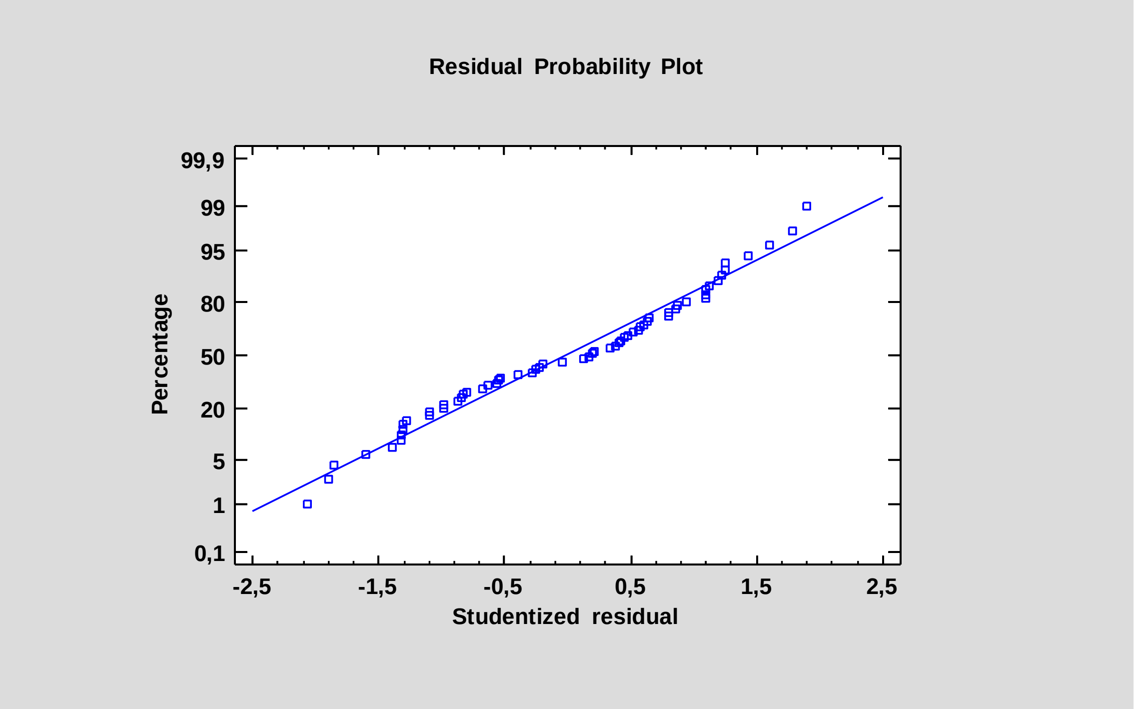


Figure 49. Residual Probability Plot for cluster O1 Design Rating.

Finally, Figure 50 shows the final regression for the design rating offices within the interval [1 - 250] m^2 after removing the outliers outside the bands. It can clearly be seen by the slope of the simple regression that the primary energy value decreases as the floor area increases.

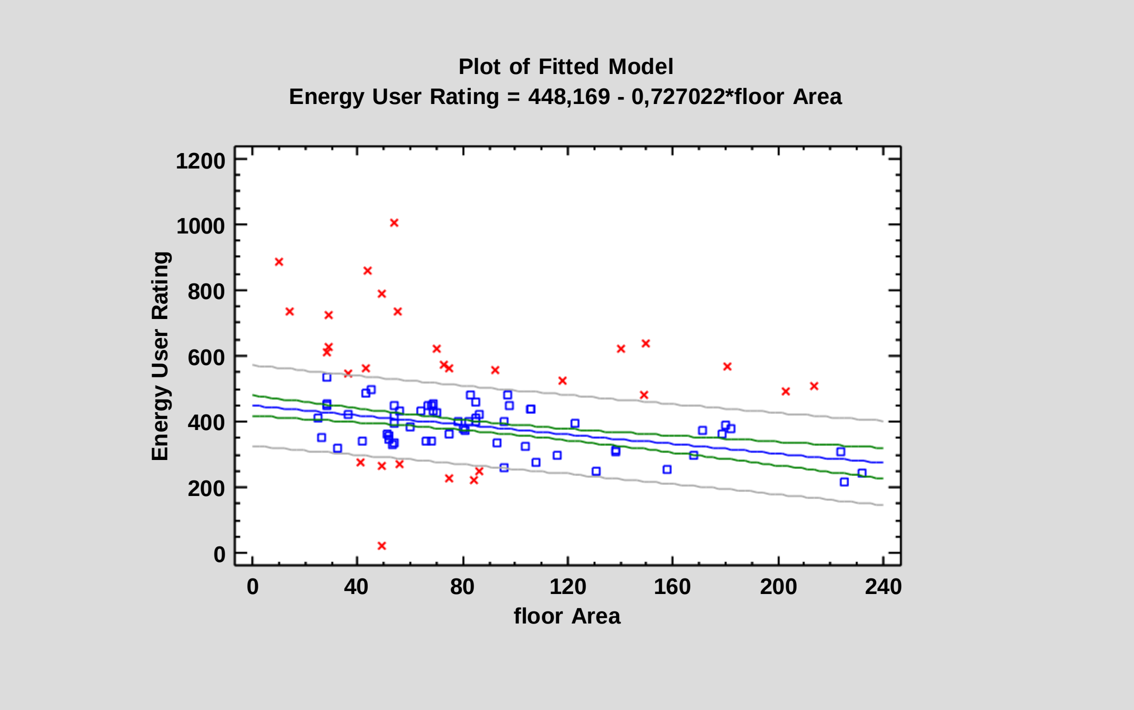


Figure 50. Dispersion graph for cluster O1 Design Rating.

4.1.4.2 RESULTS FOR DESIGN RATING CLUSTER O2

This second statistical analysis is performed for the second cluster Design Rating and floor area from 251 m^2 to 500 m^2, results are shown below in Figure 51.

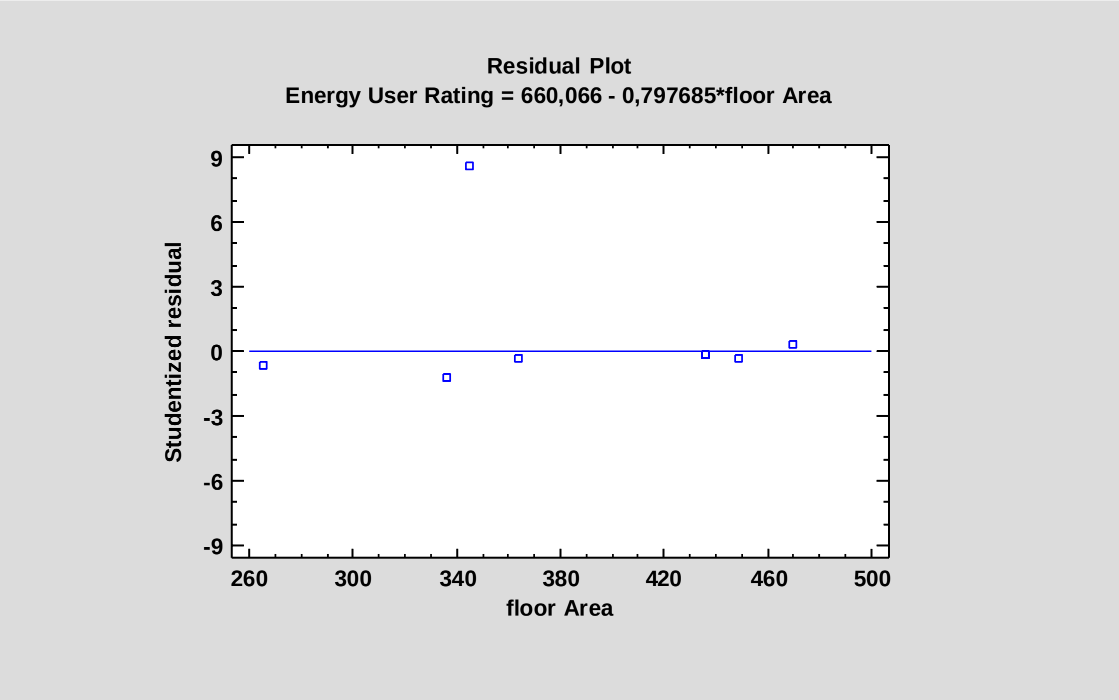


Figure 51. Plot of Residuals vs Predicted for cluster O2 Design Rating.

Figure 52 shows the residual plot after removing the outliers.

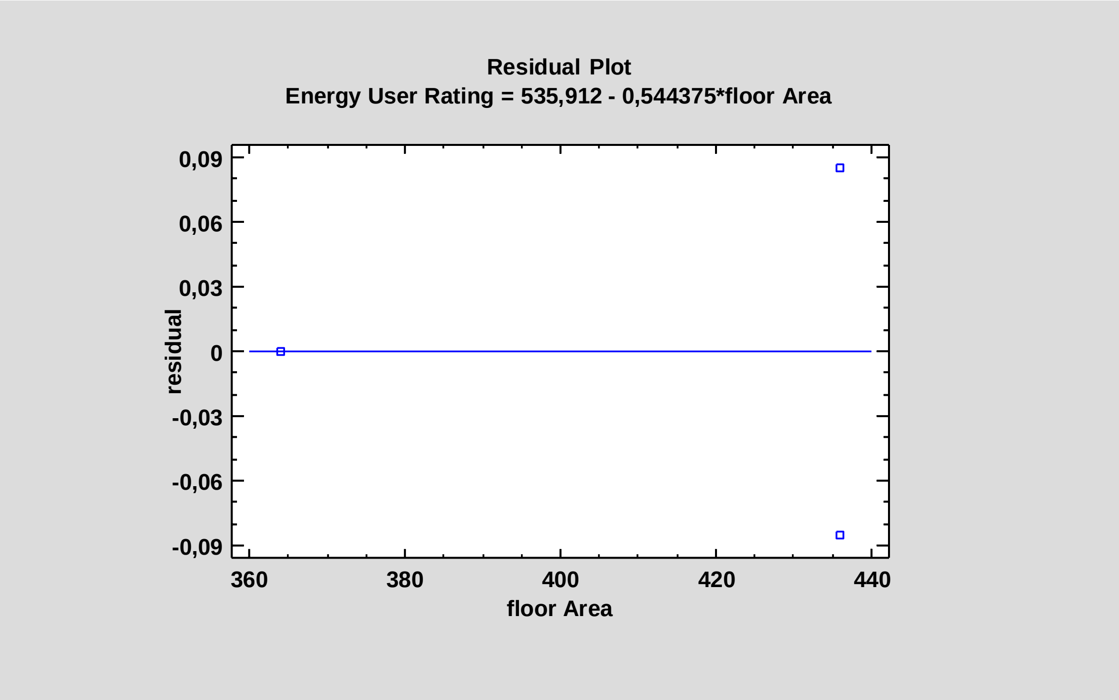


Figure 52. Final Plot of Residuals vs Predicted for cluster O2 Design Rating.

Given the lack of observations for this category, it is not possible to obtain a residual probability plot.

Finally, Figure 53 shows the final regression for the asset design type rating offices within the interval [251 – 500] m2 after removing the outliers outside the bands.

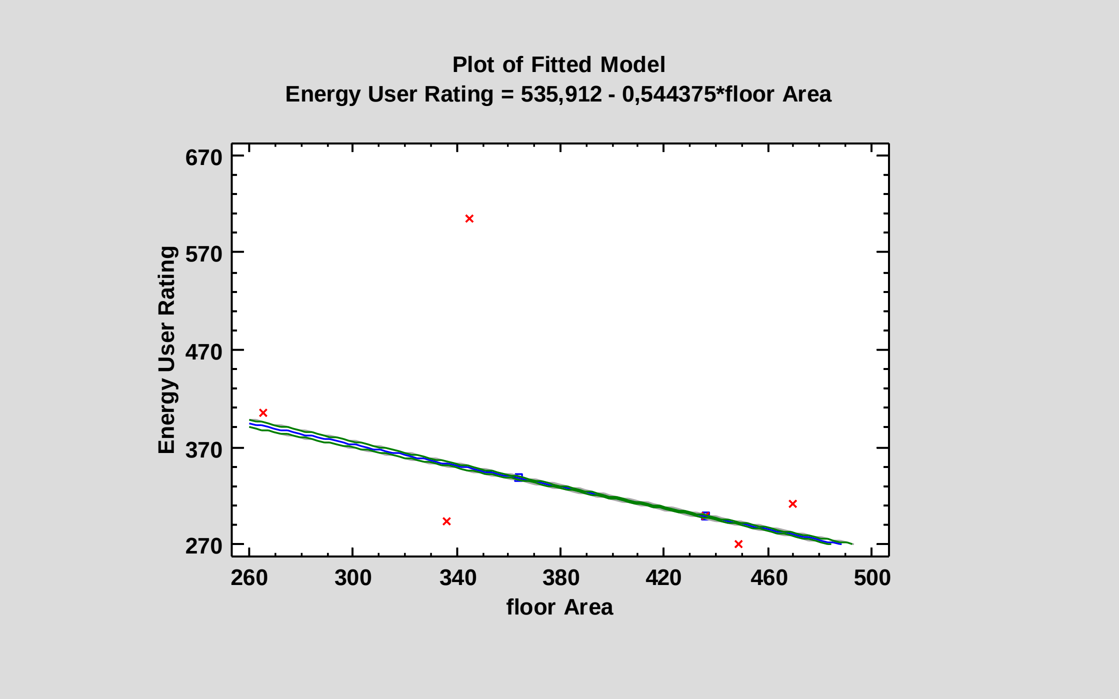


Figure 53. Dispersion graph for cluster O2 Design Rating.

4.1.4.3 RESULTS FOR DESIGN RATING CLUSTER O3

This third statistical analysis is performed for the third Asset Rating cluster whose floor area band takes from 501 m^2 to 1500 m^2, results are shown below in Figure 54.

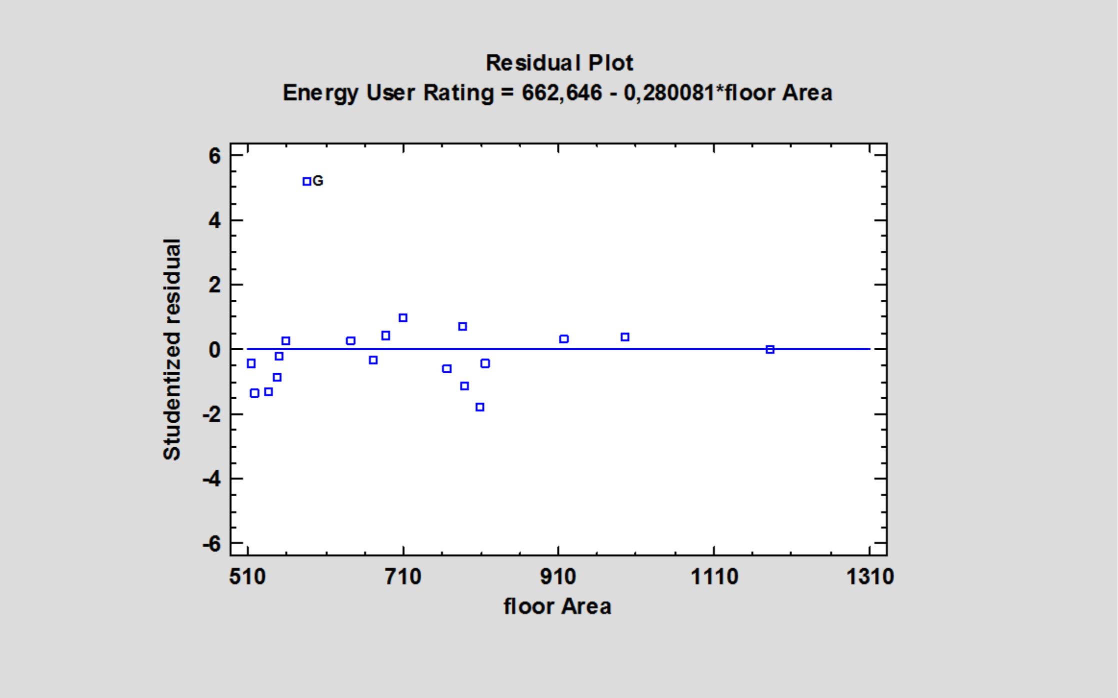


Figure 54. Plot of Residuals vs Predicted for cluster O3 Design Rating.

In this case, Figure 55, has been chosen the upper band [-3, 3] as the outlier acceptance band since otherwise we would end up with only two representative observations.

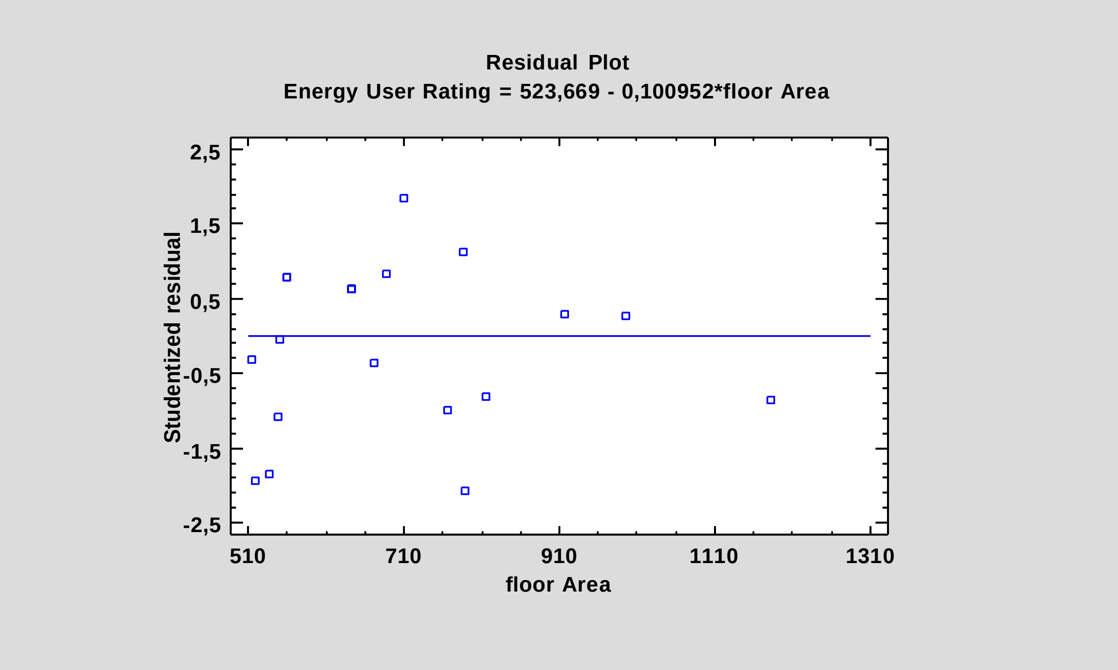


Figure 55. Final Plot of Residuals vs Predicted for cluster O3 Design Rating.

As can be seen in the normality plot, Figure 56, the observations deviate a little from the control line since, as previously mentioned, it has been decided to choose the upper limit of acceptance of outliers due to the scarcity of samples.

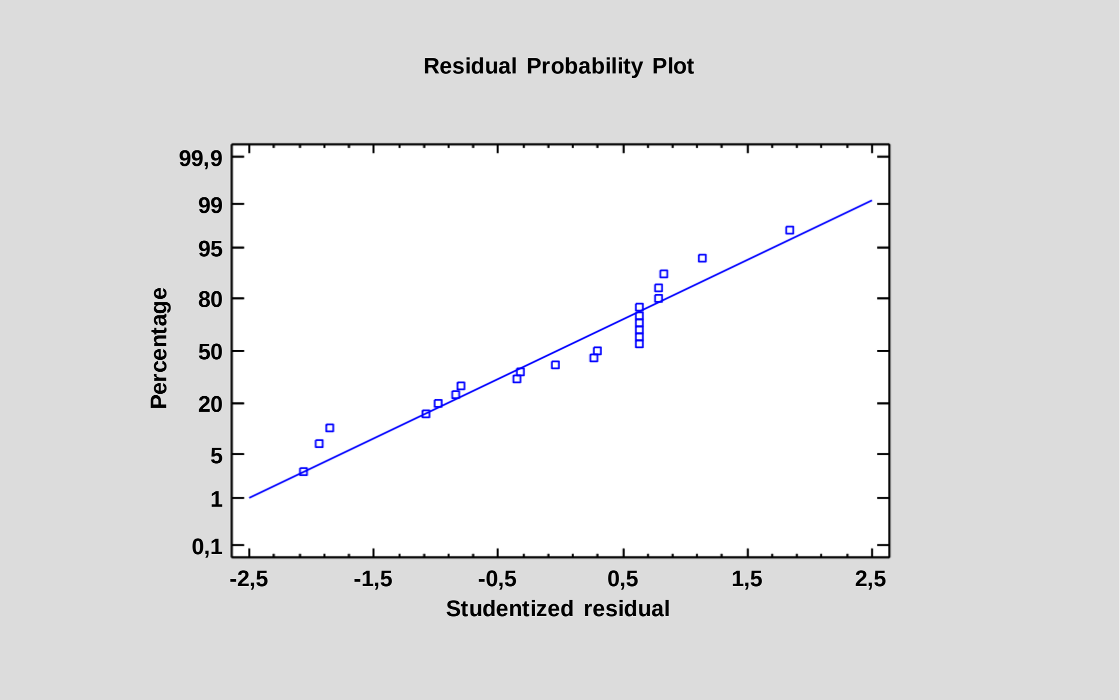


Figure 56. Residual Probability Plot for cluster O3 Design Rating.

Finally, Figure 57 shows the final regression for the design rating offices within the interval [501 – 1500] m^2 after removing the outliers outside the bands.

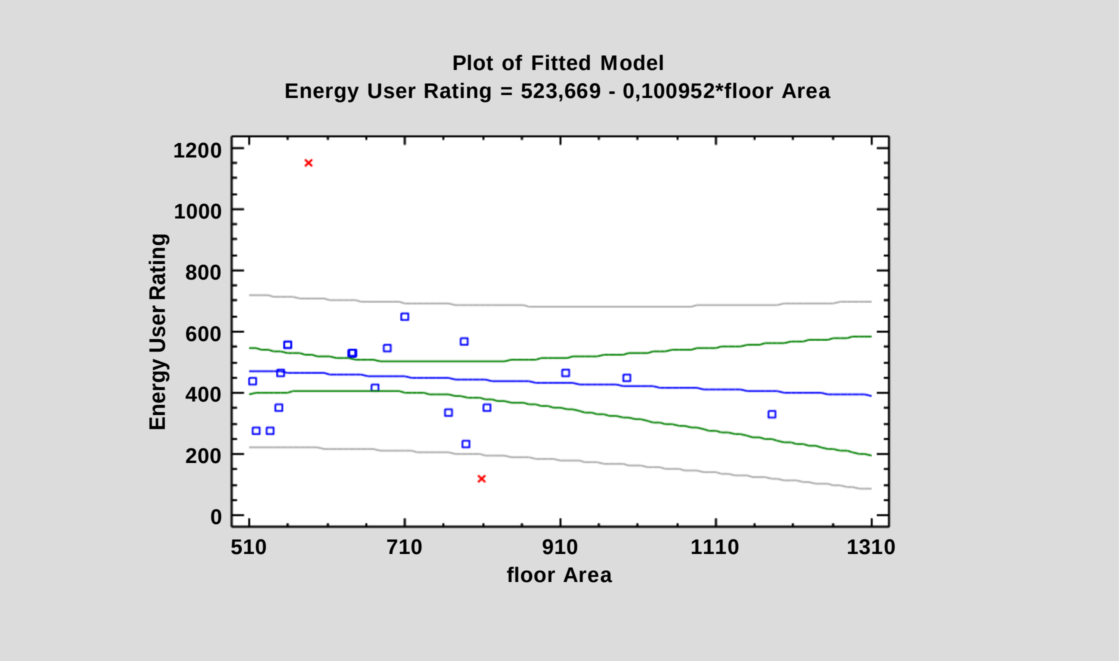


Figure 57. Dispersion graph for cluster O3 Design Rating.

4.1.4.4 RESULTS FOR DESIGN RATING CLUSTER O4

This fourth statistical analysis is performed for the fourth Design Rating cluster floor area from 1501 m^2, results are shown below in Figure 58. In this case, the upper band [-3,3] has been chosen as the outlier acceptance band due to lack of sufficient samples.

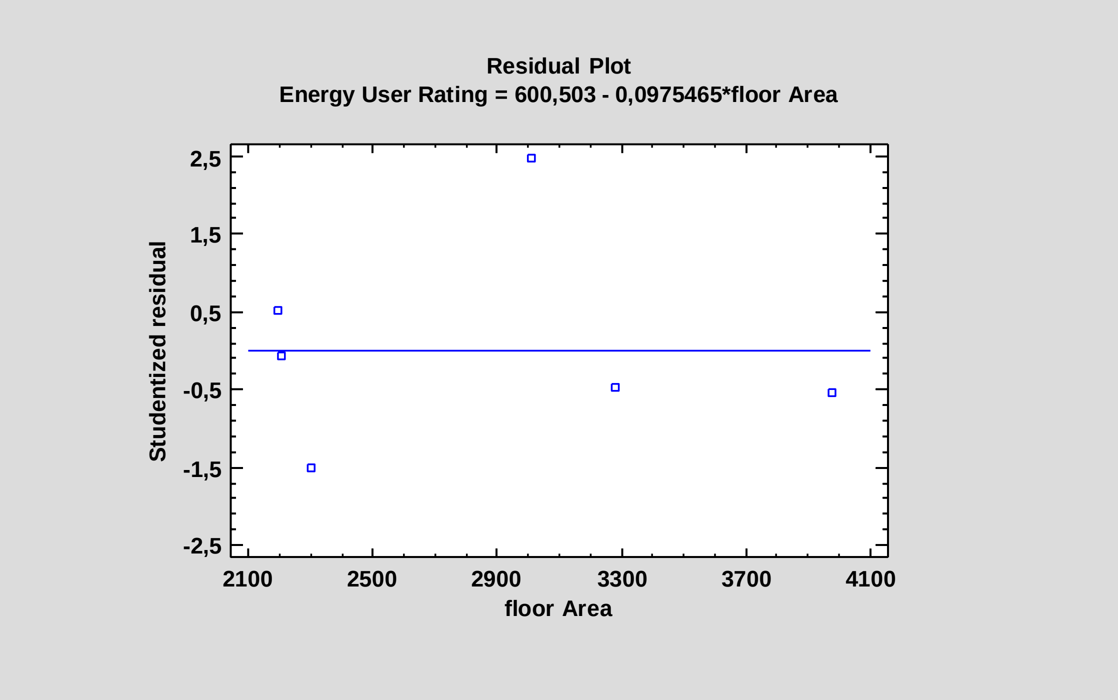


Figure 58. Final Plot of Residuals vs Predicted for cluster O4 Design Rating.

As shown in Figure 59, there are no more outliers in the model.

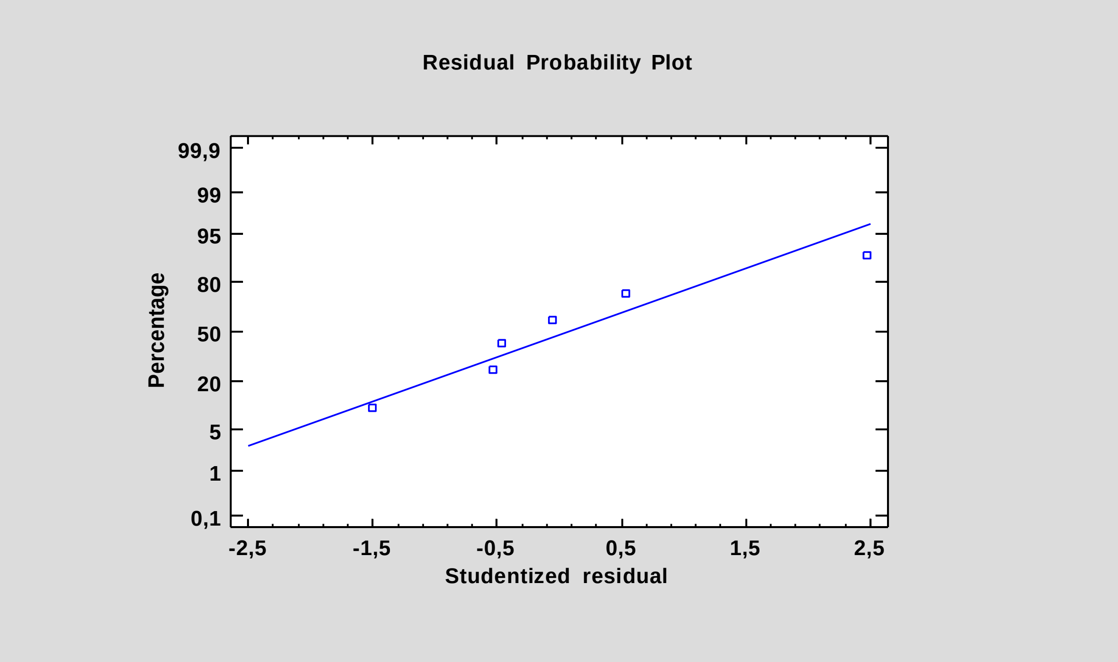


Figure 59. Residual Probability Plot for cluster O4 Design Rating.

Finally, Figure 60 shows the final regression for the design rating offices within the interval [1500+] m^2 after removing the outliers outside the bands.

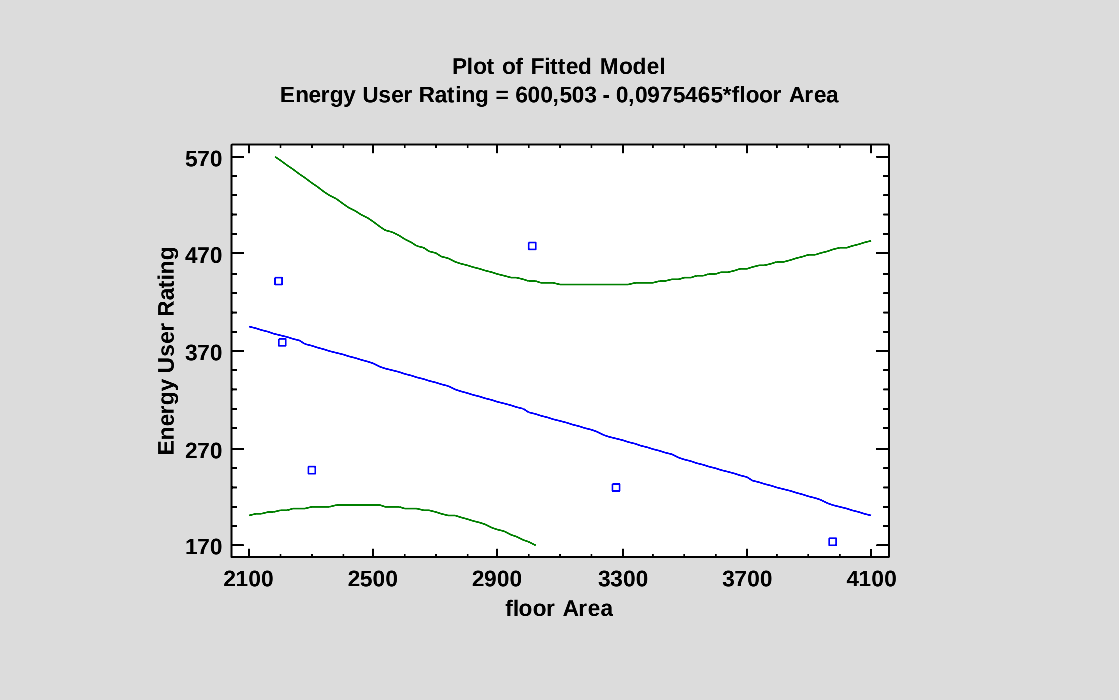


Figure 60. Dispersion graph for cluster O4 Design Rating.

4.1.5 ENERGY RATINGS FOR DESIGN RATING CLUSTERS

To facilitate the reading of the dissertation, the EPC Band ratings and their numerical equivalents will be reminded once again as shown below in Table 23.

Table 23. EPC band numeric transformation.

EPC BAND	EPC BAND NUMERIC
A, A+	1
B	2
C	3
D	4
E	5
F	6
G	7

For the first cluster, results are shown in Figure 61.

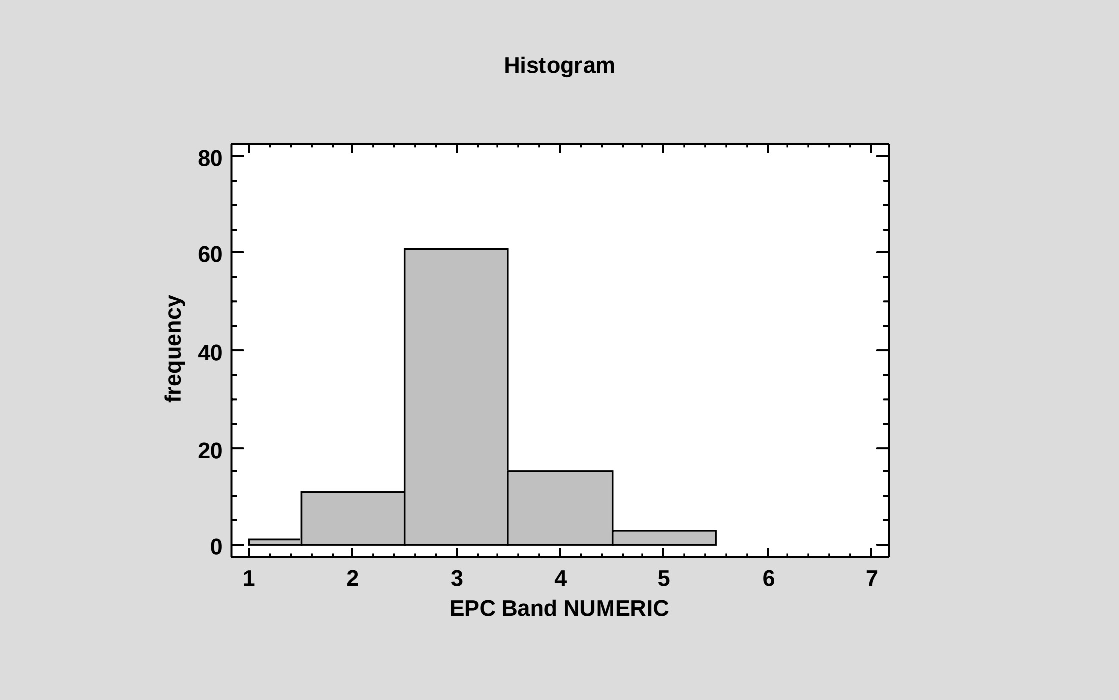


Figure 61. EPC BAND Histogram for cluster O1 Design Rating.

Table 24 shows the relative frequency of each EPC band classification.

Table 24. Frequency Tabulation for O1 Offices EPC Band.

Value=EPC BAND	***Frequency***	***Relative Frequency***	***Cumulative Frequency***	***Cum. Rel. Frequency***
1=A, A+	0	0.00	0	0.00
2=B	1	0.01	1	0.01
3=C	11	0.12	12	0.13
4=D	61	0.67	73	0.80
5=E	15	0.16	88	0.97
6=F	3	0.03	91	1.00
7=G	0	0.00	91	1.00

In the following, Figure 62 the results of the frequency histogram analysis for the second cluster are shown.

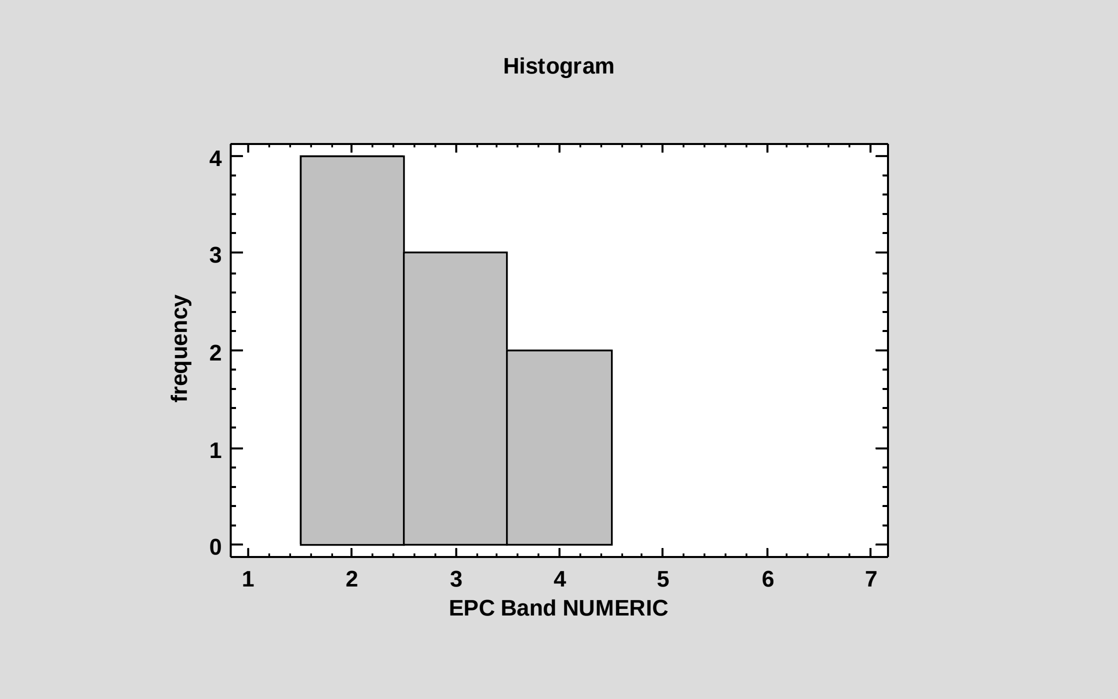


Figure 62. EPC BAND Histogram for cluster O2 Design Rating.

In the Table 25 is the relative frequency of each EPC band classification.

Table 25. Frequency Tabulation for O2 Offices EPC Band

Value=EPC BAND	***Frequency***	***Relative Frequency***	***Cumulative Frequency***	***Cum. Rel. Frequency***
1=A, A+	0	0.00	0	0.00
2=B	4	0.44	4	0.44
3=C	3	0.33	7	0.78
4=D	2	0.22	9	1.00
5=E	0	0.00	9	1.00
6=F	0	0.00	9	1.00
7=G	0	0.00	9	1.00

Figure 63 shows the results of the frequency histogram analysis for the third cluster.

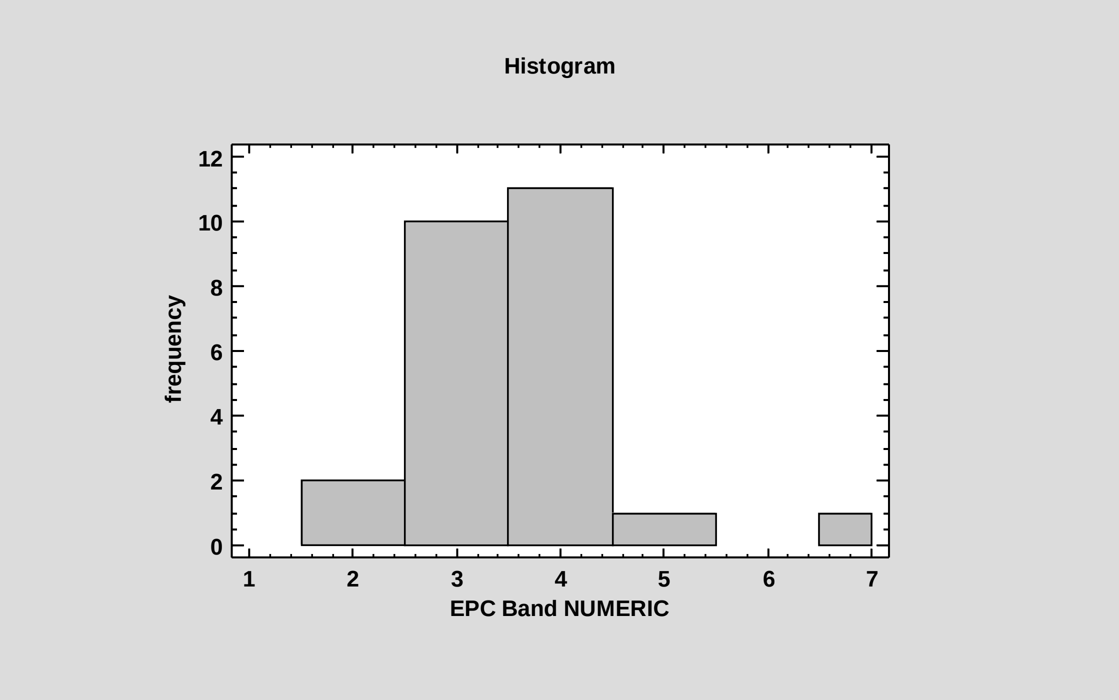


Figure 63. EPC BAND Histogram for cluster O3 Design Rating.

In the Table 26 it is seen the relative frequency of each EPC band classification.

Table 26. Frequency Tabulation for O3 Offices EPC Band.

Value=EPC BAND	***Frequency***	***Relative Frequency***	***Cumulative Frequency***	***Cum. Rel. Frequency***
1=A, A+	0	0.00	0	0.00
2=B	2	0.08	2	0.08
3=C	10	0.40	12	0.48
4=D	11	0.44	23	0.92
5=E	1	0.04	24	0.96
6=F	0	0.00	24	0.96
7=G	1	0.04	25	1.00

Finally, Figure 64 shows cluster O4 (offices with the largest surface area). It can be seen how the shape of this last cluster shows that the samples are practically efficient.

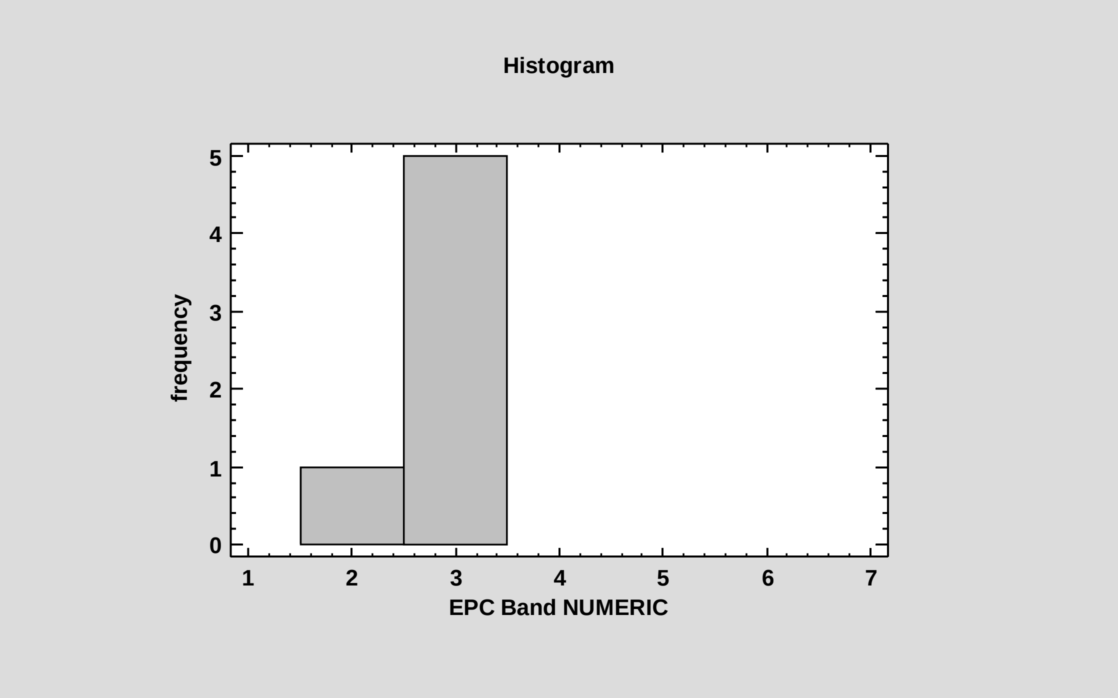


Figure 64. EPC BAND Histogram for cluster O4 Design Rating.

In the Table 27 is seen the relative frequency of each EPC band classification.

Table 27. Frequency Tabulation for O4 Offices EPC Band

Value=EPC BAND	***Frequency***	***Relative Frequency***	***Cumulative Frequency***	***Cum. Rel. Frequency***
1=A, A+	0	0.00	0	0.00
2=B	1	0.17	1	0.17
3=C	5	0.83	6	1.00
4=D	0	0.00	6	1.00
above	0	0.00	6	1.00

4.1.6 REFERENCE BUILDINGS FOR DESIGN RATING CLUSTERS

The representative building in this category is simple to define at least in terms of floor area. It is assigned an average value and then the primary energy value is calculated. The results shown below in Table 28, Table 29 and Table 30 have been gotten by performing a statistical One-Way ANOVA analysis. Due to the lack of samples the results shown in Table 31 have been calculated in Excel using the function Average.

Table 28. Representative building parameters for cluster O1 Design Rating.

Primary energy	433.630 kWh/ m^2*year
Floor Area	86.868 m^2
EPC Band	C

Table 29. Representative building parameters for cluster O2 Design Rating.

Primary energy	346,575 kWh/ m^2*year
Floor Area	393 m^2
EPC Band	C

Table 30. Representative building parameters for cluster O3 Design Rating.

Primary energy	468.247 kWh/ m^2*year
Floor Area	694.08 m^2
EPC Band	C

Table 31. Representative building parameters for cluster O4 Design Rating.

Primary energy	324.512 kWh/ m^2*year
Floor Area	2829.333 m^2
EPC Band	C

Comparing the overall energy ratings obtained from both categories (asset and design rating) shows how the Asset rating is in general less efficient than the Design Rating and higher in floor area for offices O1 and O2 (lower floor area), e.g. the asset of Office O1 is 537 kWh/ m^2*year and 104 m^2, while the Design Rating O1 is 433 kWh/ m^2*year and 86 m^2.

However, for the larger offices O3 and O4 they present more efficient values with larger floor areas, e.g. the asset of Office O3 is 326 kWh/ m^2*year and 864 m^2, while the Design Rating O3 is 468 kWh/ m^2*year and 694 m^2.

4.2 RESULTS OF THE REFERENCE BUILDINGS' ASSET OFFICES WITH DIFFERENT ENERGY EFFICIENCY MEAURES APLIED.

The results for implementing different energy efficiency measures in reference office buildings have been obtained using the SBEM-mt software, which is the official software for issuing energy performance certificates of non-residential buildings in Malta.

As a recap, four reference office buildings have been analysed. The SBEM models chosen were of offices that closely match the representative results obtained from the statistical analysis of the complete energy performance certificates database of existing office buildings, as provided by the Building and Construction Authority up to the year 2018.

The scope is to identify the most effective energy efficiency measures for each different existing office category by comparing the level of improvement in EPC Rating obtained after each simulation compared to the reference Aseet EPC Rating (without applying any measures).

Table 32 shows all the energy efficiency measures considered for the building envelope.

Table 32. Energy efficiency measures considered for the four office building categories.

Energy Efficiency Measure	Description	Details of Measure
Building Envelope	External Wall Insulation	1 cm insulation with conductivity (k = 0.035W/m*K)
		2.5 cm insulation (k = 0.035 W/m*K)
	Roof insulation	7 cm insulation (k = 0.035 W/m*K)
		10 cm insulation (k = 0.035 W/m*K)
	Glazing Improvement	Double-glazed 4mm-6mm-4mm uncoated glass, air filled, and metal frame with no thermal break
		Double-glazed 4mm-6mm-4mm low-e, air filled, metal frame with thermal break and thermally improved spacer

While the iterations took into consideration individual improvements of the above improvements as well as the combination of different measures. The choice of best energy efficiency options was based on an appreciation of both the resulting energy efficiency improvement and the projected investment to be made. For example, if a thinner wall insulation has yielded a specific improvement in the energy performance rating of the existing office, while a thicker wall insulation only slightly improves it further, then the obvious choice is to choose the thinner material, as it would be cheaper and the loss in energy efficiency benefits would only be minor.

Table 33 shows the energy efficiency measures applied for the building energy systems of the four office categories. Given that each office had a different type of air-conditioning systems, the improvements were carried out separately for each office category, separately.

Table 33. Details on energy efficiency for building energy systems measures.

Energy Efficiency Measure	**Description**	**Details of Measure**
Building Energy Systems	Air conditioners	Efficient COP values. $COP_{HEATING}$= 4.
		Efficient COP value. $COP_{COOLING}$= 5.
		Activate Local Time Control and Local Temperature Control options for all rooms.
		Change AC type from Single Duct VAV to Indoor Package Cabinet VAV.
	Lighting	T5 Fluorescent – triphosphorous - coated - high frequency ballast (lower consumption).

Depending on each reference building, the measures applied to analyse the effects of AC (air conditioning) systems on the EPC Rating of the offices were:

104 m^2 Reference Building:

Single inefficient air conditioning. Added efficient COP values ($COP_{HEATING}$=4, $COP_{COOLING}$=5) and Local Time Control and Local Temperature Control options for all rooms that were deactivated.

382 m^2 Reference Building:

Single inefficient air conditioning. Added efficient COP values ($COP_{HEATING}$=4, $COP_{COOLING}$=5) and Local Time Control and Local Temperature Control options for all rooms that were deactivated. In addition, the AC type was changed from Single Duct VAV to Indoor Package Cabinet VAV.

800 m^2 Reference Building:

Single inefficient air conditioning. Added efficient COP values ($COP_{HEATING=}$4, $COP_{COOLING}$=5) and Local Time Control options for all rooms that were deactivated.

4199 m^2 Reference Building:

Two air conditioners. Only one of the two devices is modified as the other one is energy efficient, adding the values of the other energy efficient device: $COP_{HEATING}$=4.1, $COP_{COOLING}$=5.3.

The next step was to analyse the results after modifying the lighting in each zone of each reference building by changing the lighting to T5 Fluorescent – triphosphorous - coated - high frequency ballast (lower consumption). But in the case of 104 m^2, the optimum lighting is already inputted in the reference case, so no changes are expected for lighting.

The methodology further combined the identified optimum improved building envelope measures with the optimum air conditioner and lighting options to produce the final combined optimal result for each office category.

Finally, photovoltaic (PV) systems were applied to the four reference offices to observe how they affect the EPC Rating of the simulated buildings. The resulting primary energy data after applying PV systems was checked by calculating the difference between the primary energy of the reference building when applying all measures but excluding photovoltaics and the primary energy result when applying all measures and photovoltaics. A double check was also made, as the difference should also be equal to the primary energy generated by the PV system divided by the efficiency of the electrical grid system of 0.2898.

Table 34 shows the size of the PV system capacity for each office. This was calculated based on filling 50% of the total roof area available, and this takes into consideration the need for some roof space to place other services such as water tanks and to avoid cross shading between the PV rows. The inclination of the PV modules was assumed to be 30° and the modules were assumed to be facing South.

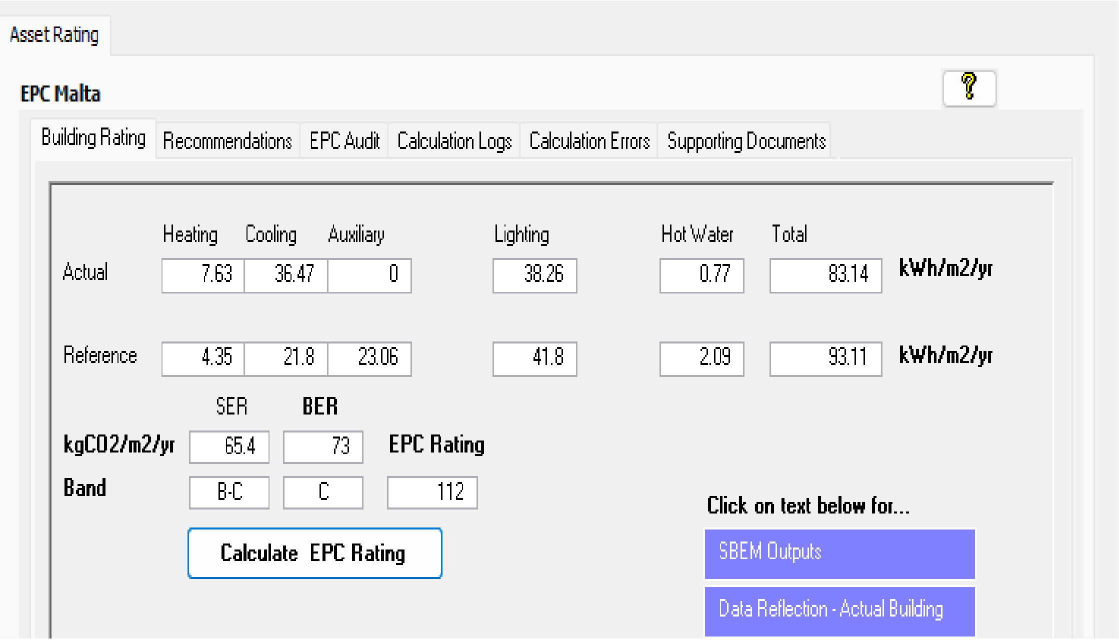
Table 34. Peak power applied for PV Systems depending of each reference building office.

Floor Area	**104 m^2**	**382 m^2**	**800 m^2**	**4199 m^2**
Peak Power	9 kWp	27 kWp	85 kWp	480 kWp

The following are the results of the simulations.

4.2.1 RESULTS FOR 104 m^2 REFERENCE BUILDING.

The first image, Figure 65, shows the results obtained (EPC Rating) for the reference building without applying any kind of measures.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	7.63	36.47	0	38.26	0.77	83.14	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	65.4	73	
Band	B-C	C	112

Figure 65. EPC Rating results for walls in 104 m2 Reference Building without any energy efficiency measures, SBEM-mt.

After applying insulation to the walls (named as 780 LS and 900 LS) in Excel, (Table 35 and Table 36), the results obtained by simulating in SBEM-mt for the EPC Rating are shown below in Figure 66 and Figure 67:

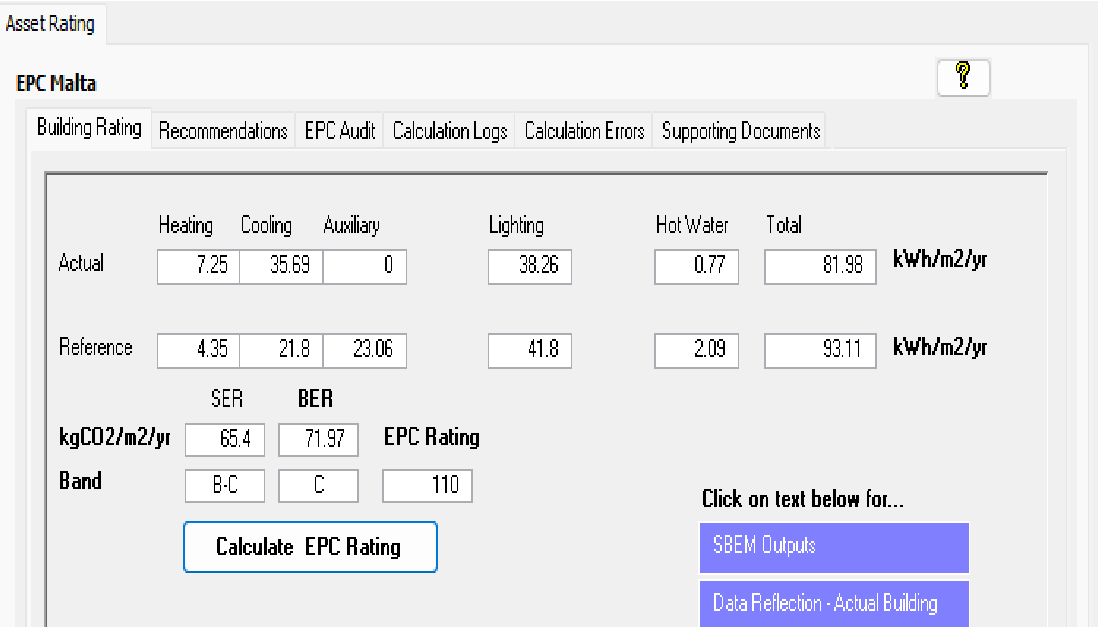
Table 35. Iterations for wall type 780 LS for 104 m2 reference building office.

104 m^2		780LS			
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance			0.060	m^{2}K/W
Element 1		0	0.18	0.000	m^{2}K/W
Element 2		0.76	1.1	0.691	m^{2}K/W
Element 3		0	0.18	0.000	m^{2}K/W
Element 4	Insulation	0	0.04	0.000	m^{2}K/W
Element 5		0	0.18	0.000	m^{2}K/W
Element 6		0	0	0.000	m^{2}K/W
Air gap resistance	Air gap	x	x	0.000	m^{2}K/W
Rsi	Internal surface resistance			0.100	m^{2}K/W
Total resistance				0.851	m^{2}K/W

Calculated U-value				**1.175**	**W/m^2K**
Element 4	Insulation	0.01	0.04		
Total resistance					
Calculated U-value				**0.908**	**W/m^2K**
Element 4	Insulation	0.025	0.04		
Total resistance					
Calculated U-value				**0.678**	**W/m^2K**

Table 36. Iterations for wall type 900 LS for 104 m2 reference building office.

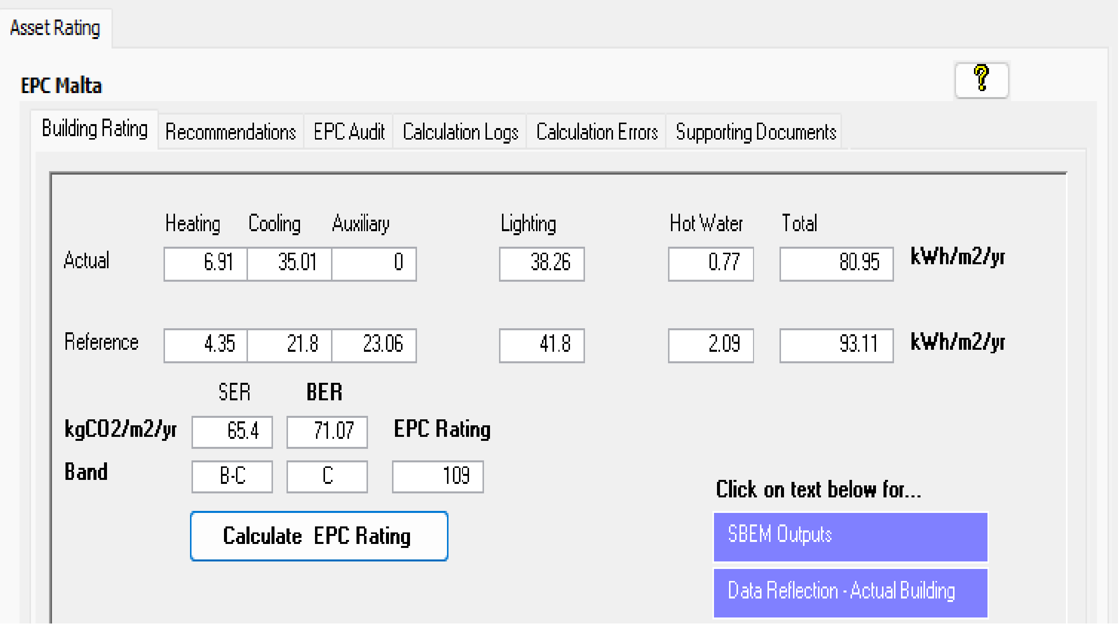
104 m^2		900LS			
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.060	m^2K/W
Element 1		0	0.18	0.000	m^2K/W
Element 2		0.84	1.1	0.764	m^2K/W
Element 3		0	0.18	0.000	m^2K/W
Element 4	Insulation	0	0.04	0.000	m^2K/W
Element 5		0	0.18	0.000	m^2K/W
Element 6		0	0	0.000	m^2K/W
Air gap resistance	Air gap	x	x	0.000	m^2K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.100	m^2K/W
Total resistance				0.924	m^2K/W
Calculated U-value				**1.083**	**W/m^2K**
Element 4	Insulation	0.01	0.04		
Total resistance					
Calculated U-value				**0.852**	**W/m^2K**
Element 4	Insulation	0.025	0.04		
Total resistance					
Calculated U-value				**0.646**	**W/m^2K**



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	7.25	35.69	0	38.26	0.77	81.98	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	65.4	71.97	
Band	B-C	C	110

Figure 66. EPC Rating results with wall insulation of 0.01 m for the 104 m^2 Reference, SBEM-mt.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	6.91	35.01	0	38.26	0.77	80.95	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

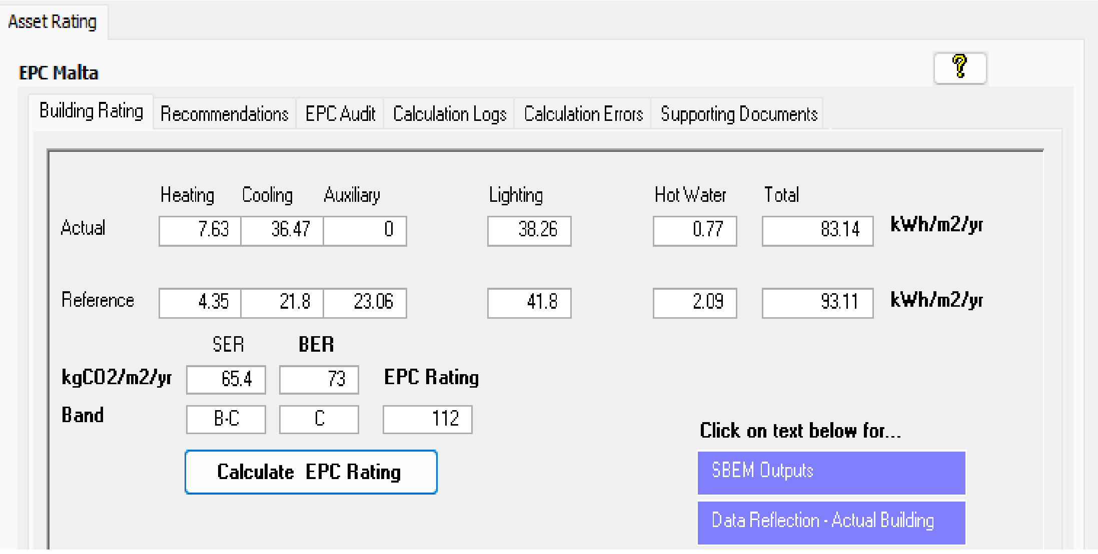
	SER	BER	EPC Rating
kgCO2/m2/yr	65.4	71.07	
Band	B-C	C	109

Figure 67. EPC Rating results with wall insulation of 0.025 m for the 104 m^2 Reference, SBEM-mt.

The following table, Table 37, shows the results obtained when simulating with roof insulation. The fact that the EPC Rating, Figure 68 and 69, do not vary with respect to the reference building without insulation may be due to two factors: firstly, the roof of the reference building taken for the simulations were already insulated or secondly, it is an office with floors above it and therefore not affected.

Table 37. Iterations for roof from 104 m2 reference building office.

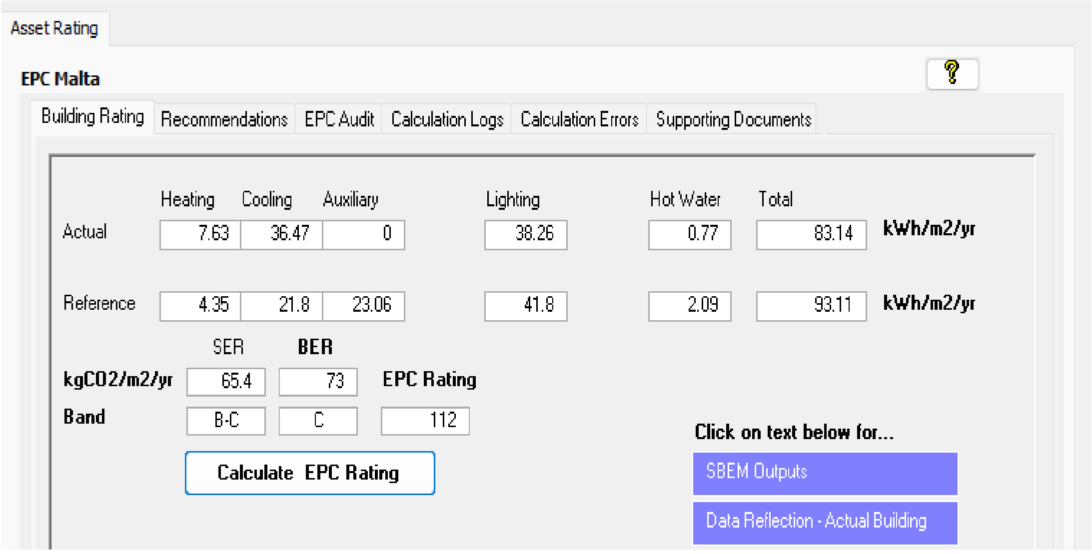
104 m^2					
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.040	m^{2}K/W
Element 1		0.004	0.23	0.017	m^{2}K/W
Element 2		0.08	0.41	0.195	m^{2}K/W
Element 3		0.08	0.8	0.100	m^{2}K/W
Element 4		0.15	2.5	0.060	m^{2}K/W
Element 5		0.012	0.04	0.300	m^{2}K/W
Element 6	Insulation	0.04	0.035	1.143	m^{2}K/W
Air gap resistance	Air gap	x	x	0.180	m^{2}K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.140	m^{2}K/W
Total resistance				2.175	m^{2}K/W
Calculated U-value				**0.460**	**W/m^{2}K**
Element 6	Insulation	0.07	0.035	2.000	m^{2}K/W
Calculated U-value				**0.330**	**W/m^{2}K**
Element 6	Insulation	0.1	0.035	2.857	m^{2}K/W
Calculated U-value				**0.257**	**W/m^{2}K**



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	7.63	36.47	0	38.26	0.77	83.14	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	65.4	73	
Band	B-C	C	112

Figure 68. EPC Rating results for roof for 104 m2 Reference Building after applying insulation with 0.07 thickness, SBEM-mt.

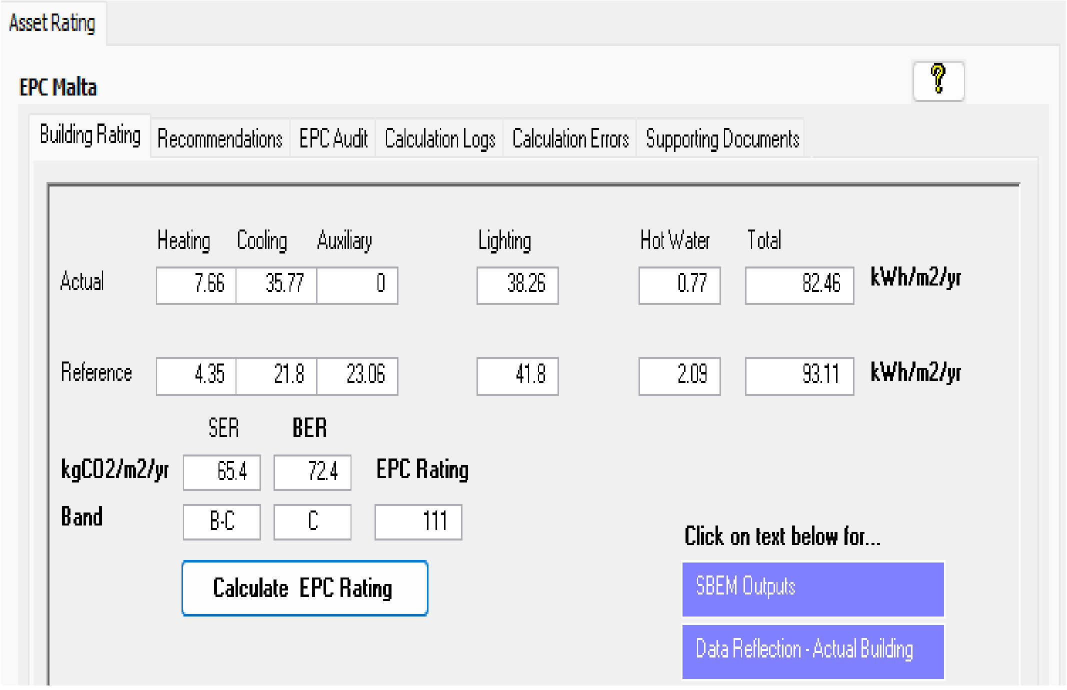


	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	7.63	36.47	0	38.26	0.77	83.14	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	65.4	73	
Band	B-C	C	112

Figure 69. EPC Rating results for roof for 104 m2 Reference Building after applying insulation with 0.01 thickness, SBEM-mt.

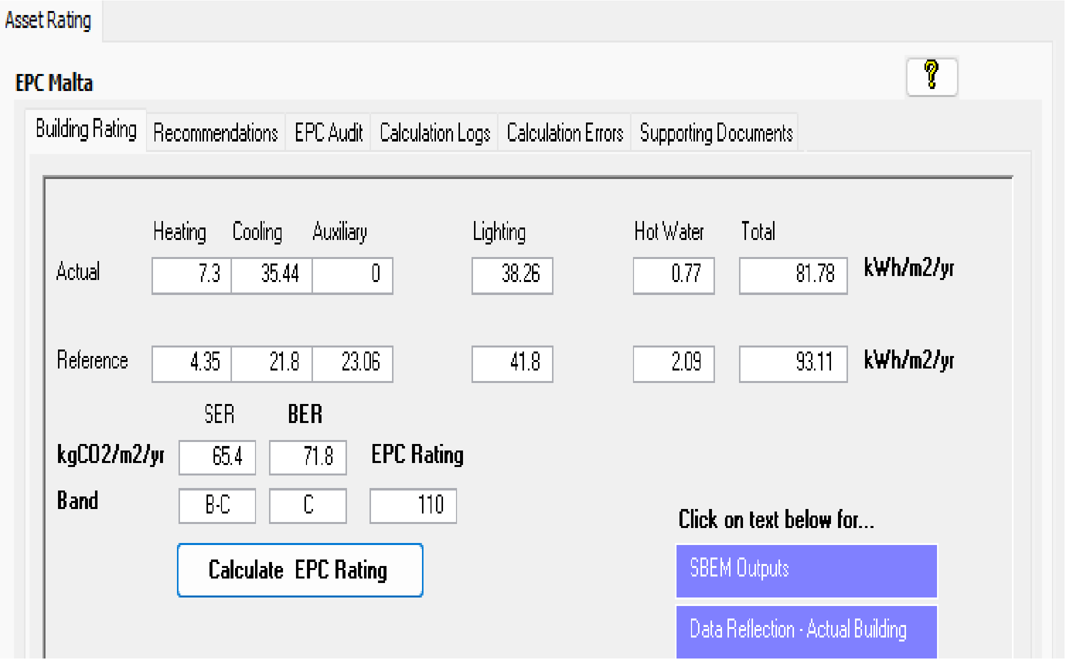
The results obtained in SBEM-mt after modifying the type of glazing and frame of the reference office are shown below, Figure 70 and Figure 71.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	7.66	35.77	0	38.26	0.77	82.46	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	65.4	72.4	
Band	B-C	C	111

Figure 70. EPC Rating results for glazing type 4-6-4 uncoated glass and frame type metal frame no thermal break thermally improved spacer for 104 m2 Reference Building, SBEM-mt.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	7.3	35.44	0	38.26	0.77	81.78	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

	SER	BER	
kgCO2/m2/yr	65.4	71.8	EPC Rating
Band	B-C	C	110

Figure 71. EPC Rating results for glazing type 4-6-4 low-e air-filled and frame type metal frame thermal break thermally improved spacer for 104 m2 Reference Building, SBEM-mt.

In the following, Figure 72, the results of combining the optimum building envelope measures are shown, where "EPC rating ref" and "primary energy ref" are the reference values and "primary energy sim" and the detailed results below are the values after applying the energy efficiency measures.

FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
104	112	286.827	274.664

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	6.57	34.01	0	38.26	0.77	79.61	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

	SER	BER	
kgCO2/m2/yr	65.4	69.9	EPC Rating
Band	B-C	C	107

Figure 72. EPC Rating results for walls, roof and glazing for 104 m2 Reference Building after applying the best percentage improvements measures, SBEM-mt.

Figure 73 below shows the results of simulating improving the energy efficiency of air conditioners for both heating and cooling.


FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
104	112	286.827	196.386

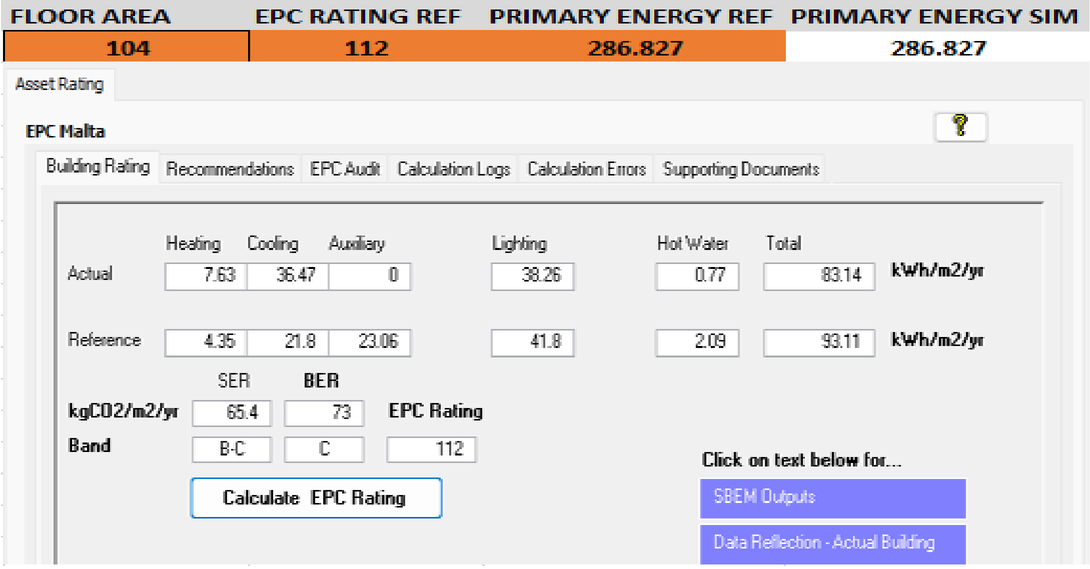
	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	3.7	14.58	0	38.26	0.39	56.92	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	65.4	49.98	
Band	B-C	B	76

Figure 73. EPC Rating results for air conditioner for 104 m2 Reference Building, SBEM-mt.

The results for improved lighting is shown in Figure 74 below.

In this case, as noted earlier at the beginning of the chapter, there is no difference with respect to the reference since all the lights were already inputted as T5 Fluorescent - triphosphorous - coated - high frequency ballast.


FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
104	112	286.827	286.827

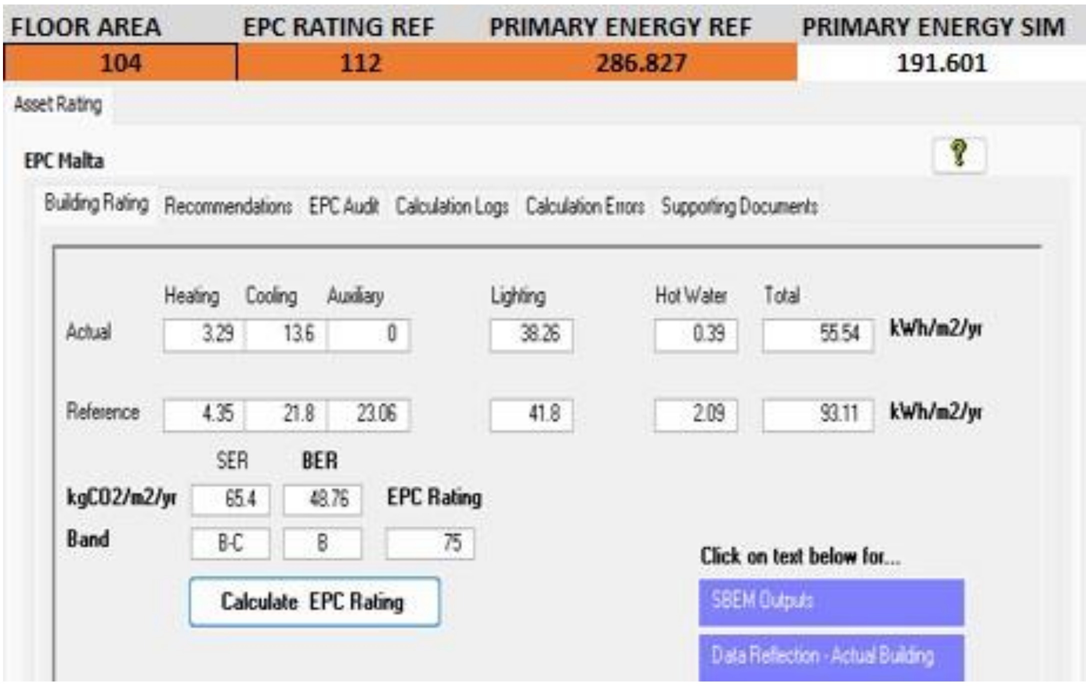
	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	7.63	36.47	0	38.26	0.77	83.14	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	65.4	73	
Band	B-C	C	112

Figure 74. EPC Rating results for lighting for 104 m2 Reference Building, SBEM-mt.

Up to now, the individual measures do not have a great impact on the primary energy or the energy efficiency rating (EPC rating) of the office in question. However, it will be shown that by applying the measures together and subsequently with the support of a photovoltaic system, a combined higher impact can be achieved.

Figure 75 below shows the results after applying the combined energy efficiency measures. It can also be seen how the primary energy and EPC rating of the office is significantly improved.



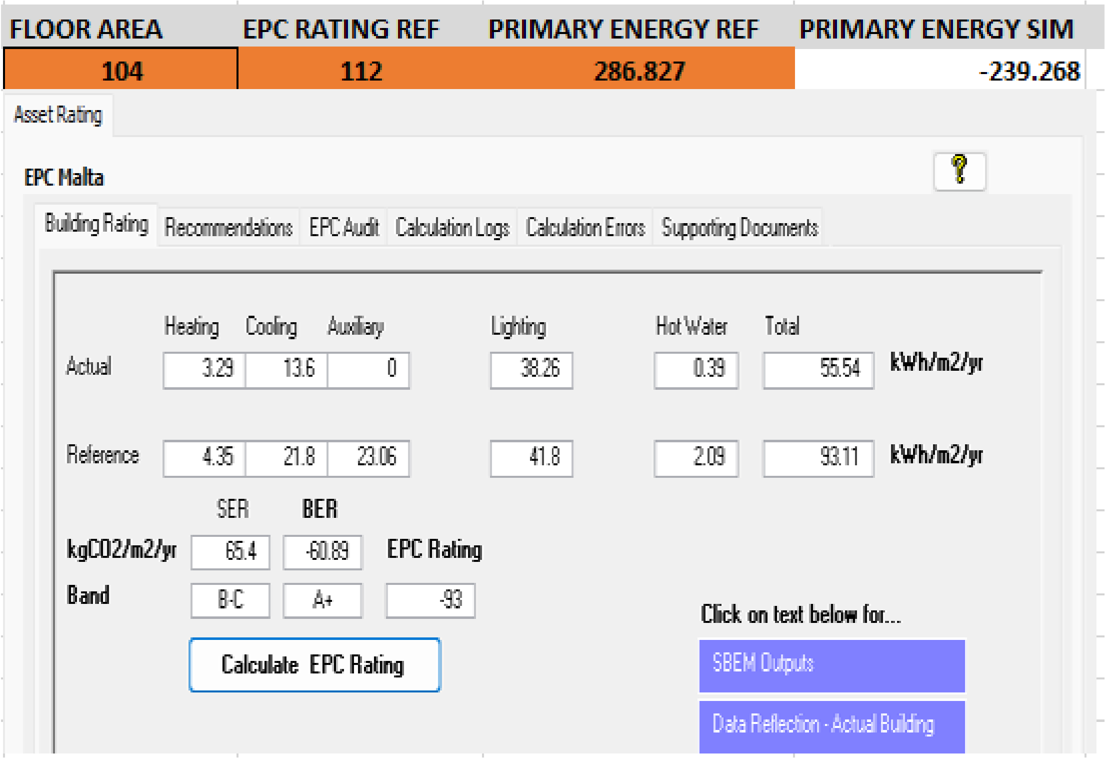
FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
104	112	286.827	191.601

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	3.29	13.6	0	38.26	0.39	55.54	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	65.4	48.76	
Band	B-C	B	75

Figure 75. EPC Rating results for all measures less PV systems for 104 m2 Reference Building, SBEM-mt.

Figure 76 shows the additional improvement to the energy performance rating after including the 9 kWp photovoltaic system. The EPC rating has turned down from 112 (class C) to -93 (class A+) pointing that not only the construction has become energetically efficient but also it produces more green energy than it consumes.



FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
104	112	286.827	-239.268

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	3.29	13.6	0	38.26	0.39	55.54	kWh/m2/yr
Reference	4.35	21.8	23.06	41.8	2.09	93.11	kWh/m2/yr

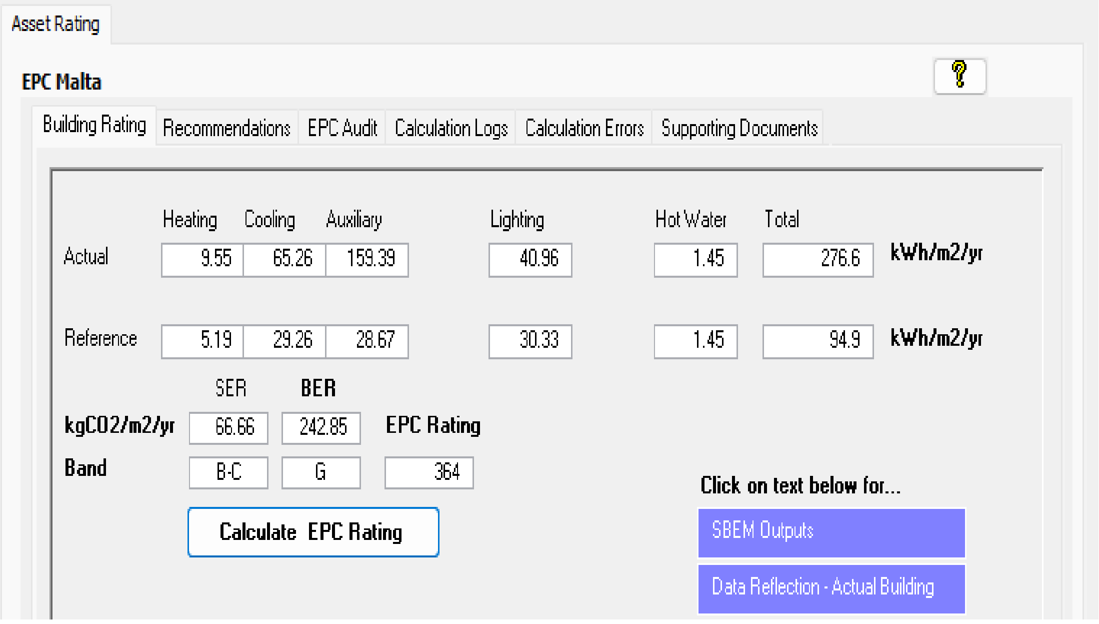
	SER	BER	EPC Rating
kgCO2/m2/yr	65.4	-60.89	
Band	B-C	A+	-93

Figure 76. EPC Rating results for all measures and PV systems for 104 m2 Reference Building, SBEM-mt.

The EPC rating has turned up from 112 (class C) to -93 (class A+) pointing that not only the construction has become energetically efficient but also produces more energy that it consumes.

4.2.2 RESULTS FOR THE 382 m^2 REFERENCE BUILDING.

The first image, Figure 77, shows the results obtained (EPC Rating) for the reference office without any energy efficiency measures.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.55	65.26	159.39	40.96	1.45	276.6	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.66	242.85	
Band	B-C	G	364

Figure 77. EPC Rating results for walls in 382 m2 Reference Building without any energy efficiency measures, SBEM-mt.

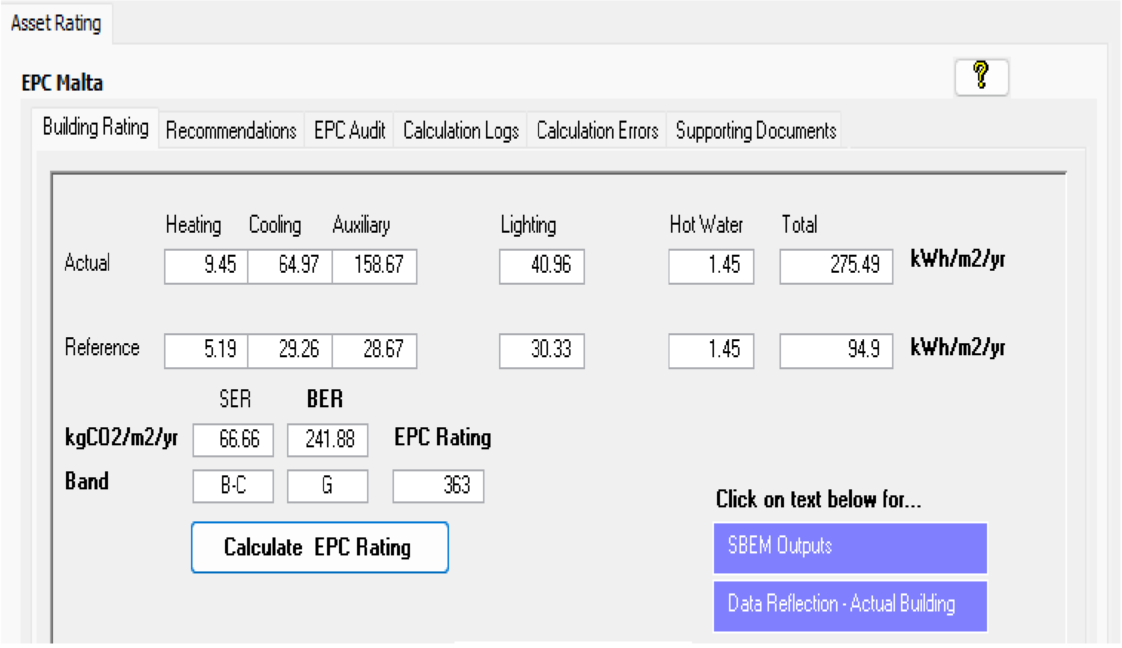
After applying insulation to the two walls (Double Façade and Single External) in Excel (Table 38 and Table 39), the results obtained by simulating in SBEM-mt for the EPC Rating are shown below in Figure 78 and Figure 79.

Table 38. Iterations for wall type Double Facade from 382 m2 reference building office.

382 m^2	**Double_facade**					
	Description	Thickness, x	conductivity, k	Fraction		
R_{se}	External surface resistance	[redacted]	[redacted]	[redacted]	0.06	m^{2}K/W
Element 1	Insulation	0	0.018	x	0.000	m^{2}K/W
Element 2		0.15	1.1	x	0.136	m^{2}K/W
Air gap resistance	Air gap	0.05	x	x	0.18	m^{2}K/W
Element 3		0.15	1.1	x	0.136	m^{2}K/W
Element 4	Insulation	0	0.018	x	0.000	m^{2}K/W
R_{si}	Internal surface resistance	[redacted]	[redacted]	[redacted]	0.1	m^{2}K/W
Element 5	Bond stone	0.35	1.1	0.1	0.318	m^{2}K/W
Resistance R1					0.613	m^{2}K/W
Resistance R2					0.478	m^{2}K/W
Resistance R_{upper}					0.596	m^{2}K/W
Resistance R_{lower}					0.572	m^{2}K/W
Total resistance					0.584	m^{2}K/W
Calculated U-value (with bond stone)					**1.730**	**W/m^{2}K**
Element 1	Insulation	0.01	0.04	x	0.250	m^{2}K/W
Element 4	Insulation	0	0.018	x	0.000	m^{2}K/W
Total resistance					0.582	m^{2}K/W
Calculated U-value (with bond stone)					**1.719**	**W/m^{2}K**
Element 1	Insulation	0.025	0.04	x	0.625	m^{2}K/W
Element 4	Insulation	0	0.018	x	0.000	m^{2}K/W
Total resistance					0.958	m^{2}K/W
Calculated U-value (with bond stone)					**1.044**	**W/m^{2}K**

Table 39. Iterations for wall type Single External from 382 m2 reference building office.

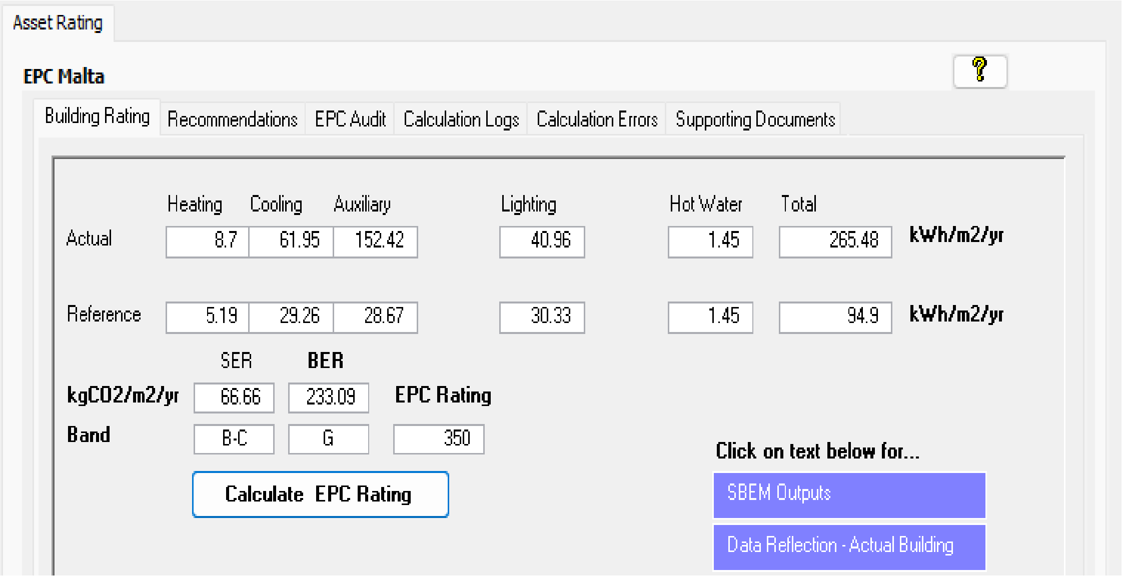
382 m^2	**Single_external**				
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.060	m^{2}K/W
Element 1		0	0.18	0.000	m^{2}K/W
Element 2		0.18	1.1	0.164	m^{2}K/W
Element 3		0	0.18	0.000	m^{2}K/W
Element 4	Insulation	0	0.04	0.000	m^{2}K/W
Element 5		0	0.18	0.000	m^{2}K/W
Element 6		0	0	0.000	m^{2}K/W
Air gap resistance	Air gap	x	x	0.000	m^{2}K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.100	m^{2}K/W
Total resistance				0.324	m^{2}K/W
Calculated U-value				**3.090**	**W/m^{2}K**
Element 4	Insulation	0.01	0.04		
Total resistance					
Calculated U-value				**1.743**	**W/m^{2}K**
Element 4	Insulation	0.025	0.04		
Total resistance					
Calculated U-value				**1.054**	**W/m^{2}K**



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.45	64.97	158.67	40.96	1.45	275.49	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.66	241.88	
Band	B-C	G	363

Figure 78. EPC Rating results for walls in 382 m2 Reference Building after applying insulation with 0.01 thickness, SBEM-mt.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	8.7	61.95	152.42	40.96	1.45	265.48	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

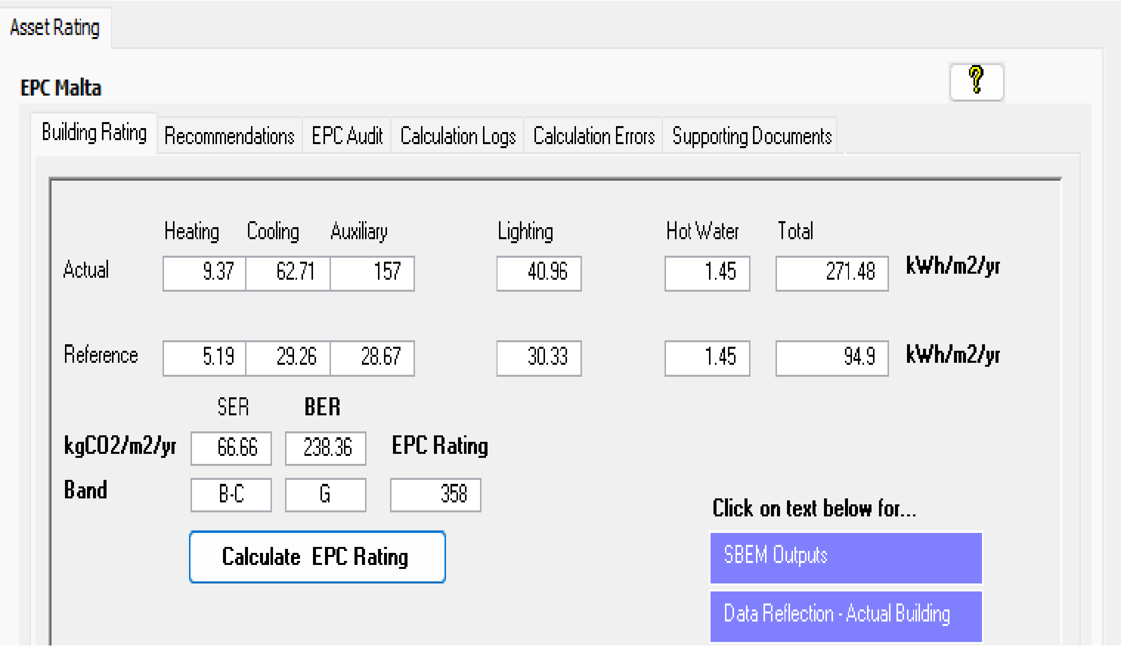
	SER	BER	EPC Rating
kgCO2/m2/yr	66.66	233.09	
Band	B-C	G	350

Figure 79. EPC Rating results for walls in 382 m2 Reference Building after applying insulation with 0.025 thickness, SBEM-mt.

The following table, Table 40, shows the results obtained when simulating with roof insulation, Figures 80 and 81.

Table 40. Iterations for roof from 382 m2 reference building office.

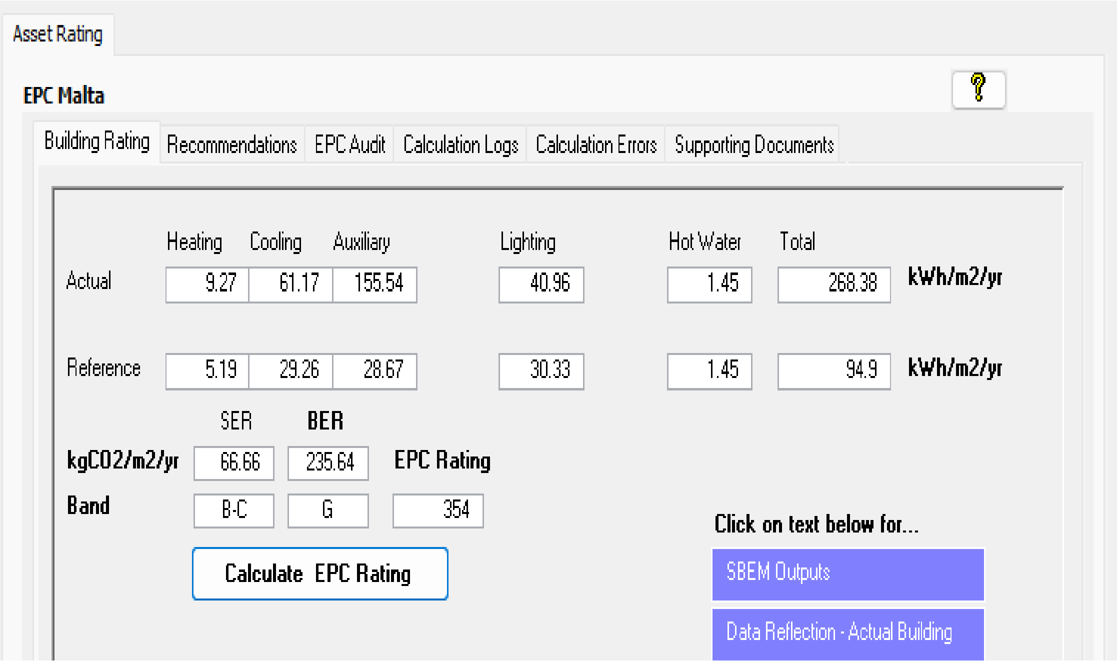
382 m^2					
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.040	m^{2}K/W
Element 1		0.004	0.23	0.017	m^{2}K/W
Element 2		0.08	0.41	0.195	m^{2}K/W
Element 3		0.08	0.8	0.100	m^{2}K/W
Element 4		0.15	2.5	0.060	m^{2}K/W
Element 5		0.012	0.04	0.300	m^{2}K/W
Element 6	Insulation	0.04	0.035	1.143	m^{2}K/W
Air gap resistance	Air gap	x	x	0.180	m^{2}K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.140	m^{2}K/W
Total resistance				2.175	m^{2}K/W
Calculated U-value				**0.460**	**W/m^2 K**
Element 6	Insulation	0.07	0.035	2.000	m^{2}K/W
Calculated U-value				**0.330**	**W/m^2 K**
Element 6	Insulation	0.1	0.035	2.857	m^{2}K/W
Calculated U-value				**0.257**	**W/m^2 K**



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.37	62.71	157	40.96	1.45	271.48	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.66	238.36	
Band	B-C	G	358

Figure 80. EPC Rating results for roof in 382 m2 Reference Building after applying insulation with 0.07 thickness, SBEM-mt.

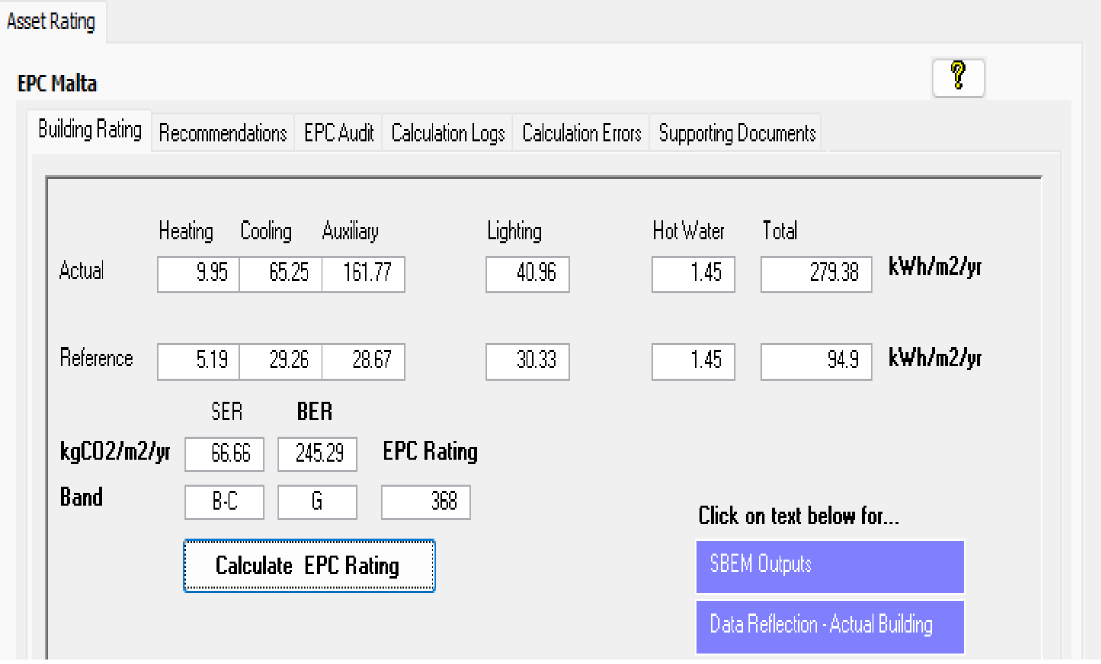


	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.27	61.17	155.54	40.96	1.45	268.38	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.66	235.64	
Band	B-C	G	354

Figure 81. EPC Rating results for roof in 382 m2 Reference Building after applying insulation with 0.01 thickness, SBEM-mt.

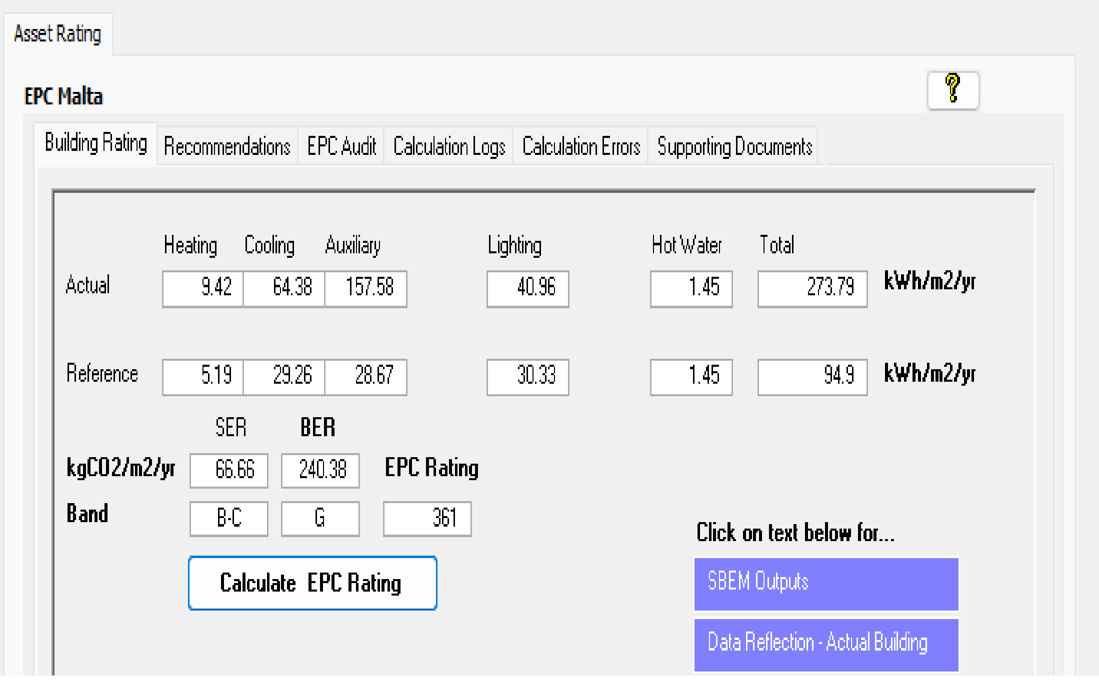
The results obtained in SBEM-mt after modifying the type of glazing and frame of the reference office are shown below, Figure 82 and Figure 83.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.95	65.25	161.77	40.96	1.45	279.38	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.66	245.29	
Band	B-C	G	368

Figure 82. EPC Rating results for glazing type 4-6-4 uncoated glass and frame type metal frame no thermal break thermally improved spacer in 382 m2 Reference Building, SBEM-mt.

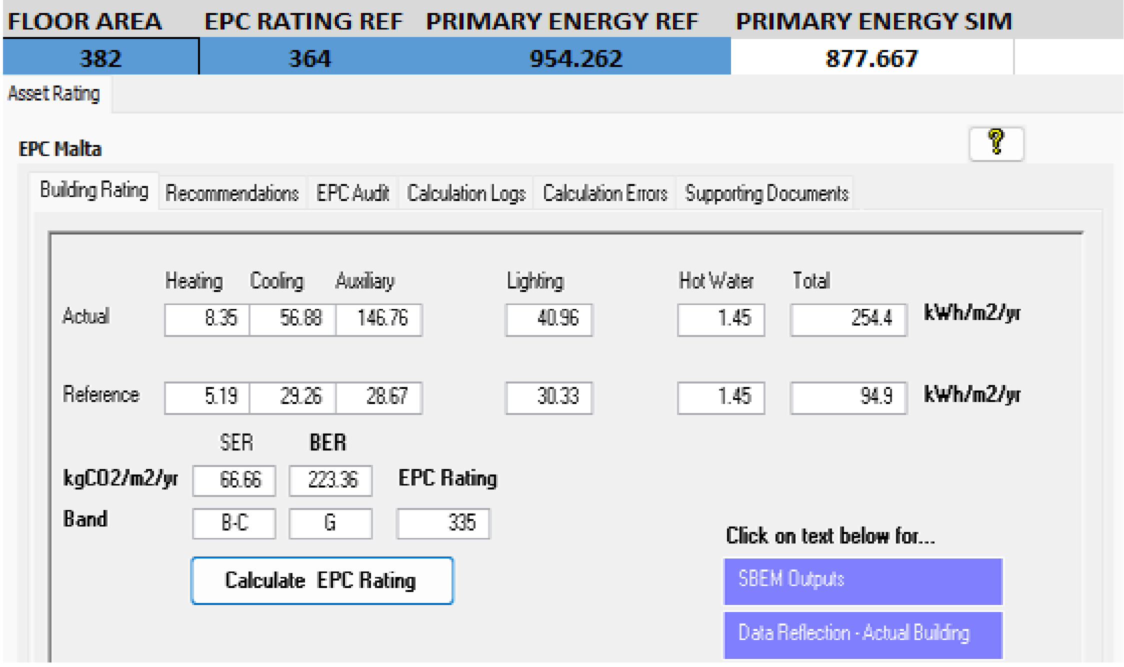


	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.42	64.38	157.58	40.96	1.45	273.79	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.66	240.38	
Band	B-C	G	361

Figure 83. EPC Rating results for glazing type 4-6-4 low-e air-filled and frame type metal frame thermal break thermally improved spacer in 382 m2 Reference Building, SBEM-mt.

Figure 84 shows the combined improvement achieved for building envelope optimum energy efficiency measures, where “EPC rating ref” and “primary energy ref” are the reference values and “primary energy sim” together with the detailed results show the final outcome of building envelope combined improvements.



FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
382	364	954.262	877.667

Asset Rating

EPC Malta

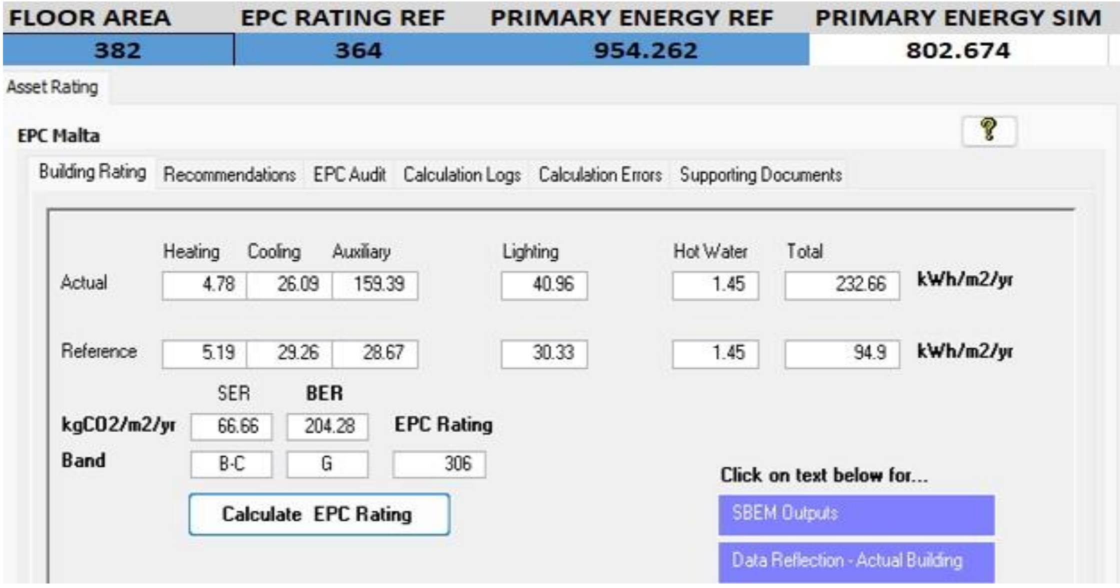
Building Rating | Recommendations | EPC Audit | Calculation Logs | Calculation Errors | Supporting Documents

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	8.35	56.88	146.76	40.96	1.45	254.4	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

	SER	BER	EPC Rating
kgC02/m2/yr	66.66	223.36	
Band	B-C	G	335

Figure 84. EPC Rating results for walls, roof and glazing in 382 m2 Reference Building after applying the best percentage improvements measures, SBEM-mt.

Figure 85 below shows the results of simulating improved air conditioners for both heating and cooling.



FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
382	364	954.262	802.674

Asset Rating

EPC Malta

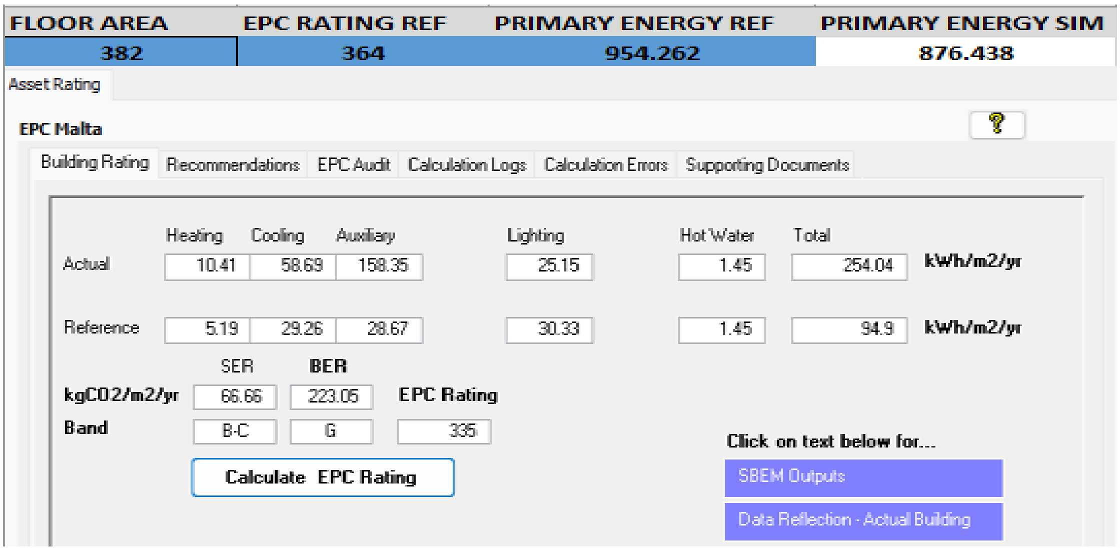
Building Rating | Recommendations | EPC Audit | Calculation Logs | Calculation Errors | Supporting Documents

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	4.78	26.09	159.39	40.96	1.45	232.66	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

	SER	BER	EPC Rating
kgC02/m2/yr	66.66	204.28	
Band	B-C	G	306

Figure 85. EPC Rating results for air conditioner in 382 m2 Reference Building, SBEM-mt.

The results of improved lighting is shown in Figure 86 below.



FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
382	364	954.262	876.438

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	10.41	58.69	158.35	25.15	1.45	254.04	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

	SER	BER	
kgCO2/m2/yr	66.66	223.05	EPC Rating
Band	B-C	G	335

Figure 86. EPC Rating results for lighting in 382 m2 Reference Building, SBEM-mt.

When looking at the above results, individual improvements of measures do not significantly reduce energy consumption. However, it will be shown that by applying the measures together and subsequently with the support of a photovoltaic system, the expected results can be achieved.

Figure 87 below shows the results after applying the best building envelope measures, increased energy efficiency of the AC and lighting. It can also be seen how the primary energy and EPC rating of the office is significantly improved.

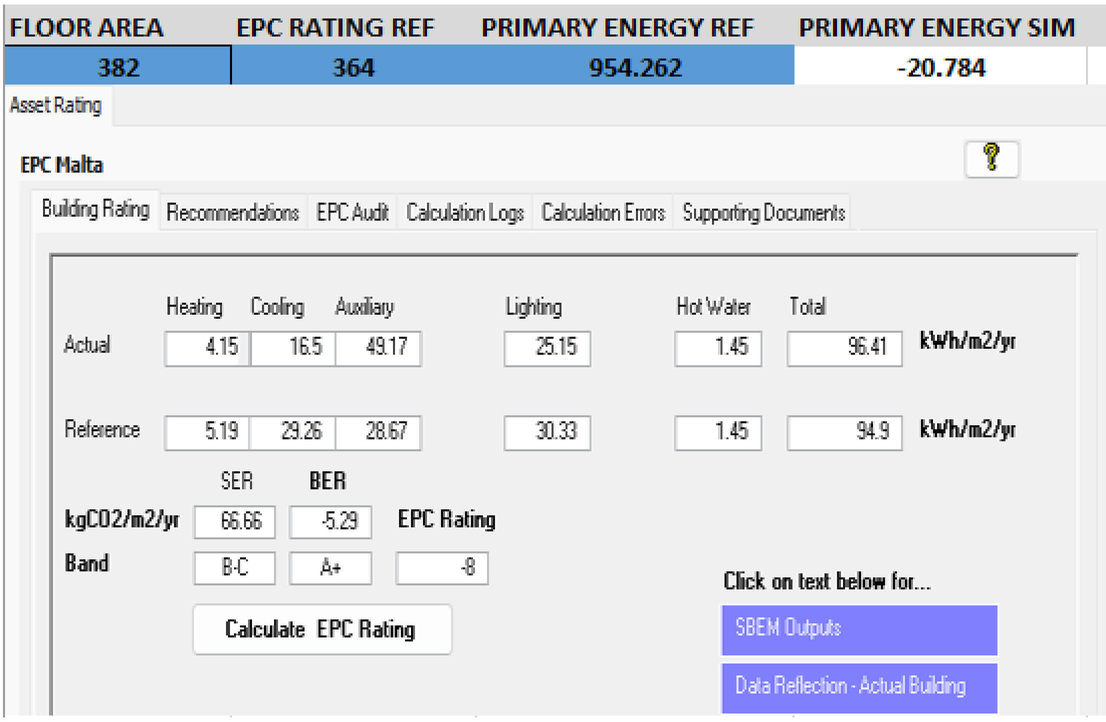
FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
382	364	954.262	680.136

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	4.71	20.11	145.73	25.15	1.45	197.14	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

	SER	BER	
kgCO2/m2/yr	66.66	173.09	EPC Rating
Band	B-C	F	260

Figure 87. EPC Rating results for all measures less PV systems in 104 m2 Reference Building, SBEM-mt.

Figure 88 shows how after applying all the measures to improve the energy efficiency of the office and subsequently adding a 27 kWp photovoltaic system very promising results were achieved. The EPC rating has improved from 364 (class G) to -8 (class A+) pointing that not only the construction has become energetically efficient but the office will also produce more green energy that it requires.



FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
382	364	954.262	-20.784

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	4.15	16.5	49.17	25.15	1.45	96.41	kWh/m2/yr
Reference	5.19	29.26	28.67	30.33	1.45	94.9	kWh/m2/yr

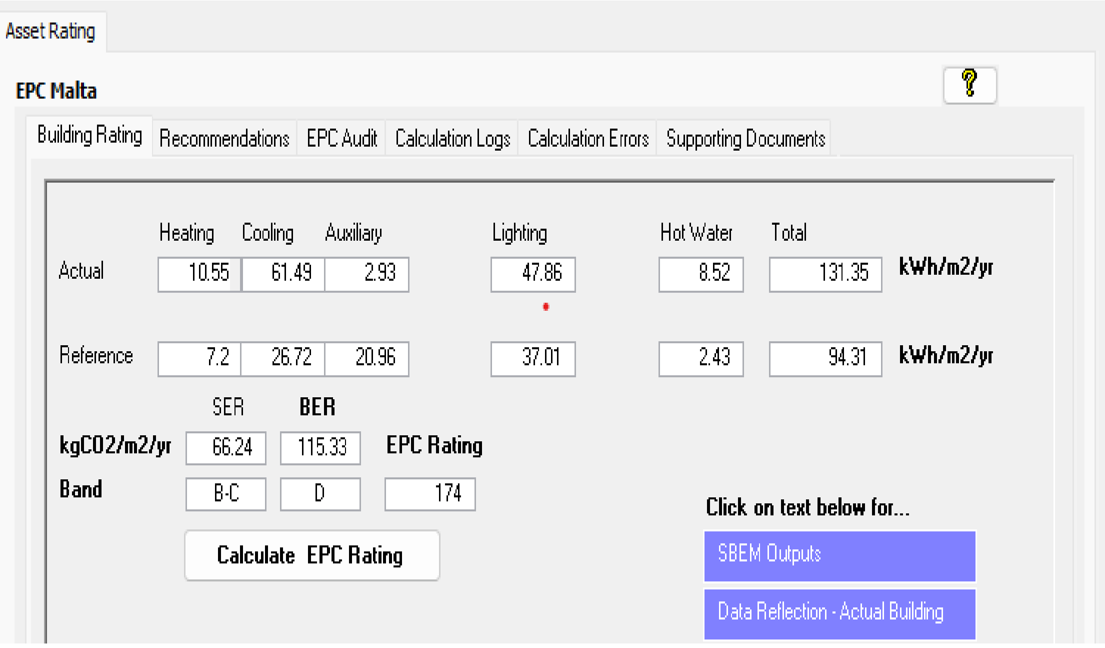
	SER	BER	EPC Rating
kgC02/m2/yr	66.66	-5.29	
Band	B-C	A+	-8

Figure 88. EPC Rating results for all measures and PV systems in 382 m2 Reference Building, SBEM-mt.

From the four cases studied, this one is remarkably the most appropriate to demonstrate the potential for improving the energy efficiency of offices. As can be seen, by correctly studying each case and applying efficient measures for each reference building, offices with the worst possible energy classification (G) can achieve an unbeatable energy classification (A+).

4.2.3 RESULTS FOR 800 m^2 REFERENCE BUILDING.

The first image, Figure 89, shows the results obtained (EPC Rating) for the reference office with no energy efficiency interventions.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	10.55	61.49	2.93	47.86	8.52	131.35	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.24	115.33	
Band	B-C	D	174

Figure 89. EPC Rating results for walls in 382 m2 Reference Building without energy efficiency measures, SBEM-mt.

The office had four different types of external walls named Franka 230, Franka 360, Franka 800, Franka 900, for which two levels of insulation were applied as shown in Table 41, Table 42, Table 43 and Table 44. The results obtained by simulating in SBEM-mt for the EPC Rating are shown below in Figure 90 and Figure 91.

Table 41. Iterations for wall type Franka 230 from 800 m2 reference building office.

800 m^{2}	**F_230**				
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.060	m^{2}K/W
Element 1		0	0.18	0.000	m^{2}K/W
Element 2		0.23	1.1	0.209	m^{2}K/W
Element 3		0	0.18	0.000	m^{2}K/W
Element 4	Insulation	0	2.3	0.000	m^{2}K/W
Element 5		0	0.18	0.000	m^{2}K/W
Element 6		0	0	0.000	m^{2}K/W
Air gap resistance	Air gap	x	x	0.000	m^{2}K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.100	m^{2}K/W
Total resistance				0.369	m^{2}K/W
Calculated U-value				**2.709**	**W/m^{2}K**
Element 4	Insulation	0.01	0.04		
Total resistance					
Calculated U-value				**1.615**	**W/m^{2}K**
Element 4	Insulation	0.025	0.04		
Total resistance					
Calculated U-value				**1.006**	**W/m^{2}K**

Table 42. Iterations for wall type Franka 360 from 800 m2 reference building office.

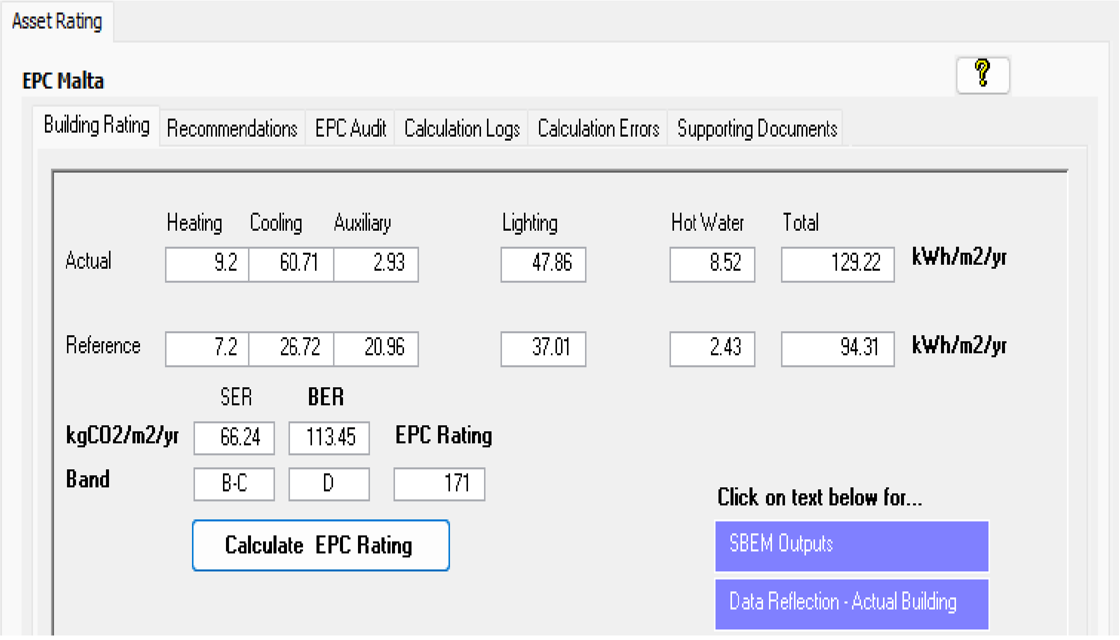
800 m^2	**F_360**				
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.060	m^{2}K/W
Element 1		0	0.18	0.000	m^{2}K/W
Element 2		0.38	1.1	0.345	m^{2}K/W
Element 3		0	0.18	0.000	m^{2}K/W
Element 4	Insulation	0	0.04	0.000	m^{2}K/W
Element 5		0	0.18	0.000	m^{2}K/W
Element 6		0	0	0.000	m^{2}K/W
Air gap resistance	Air gap	x	x	0.000	m^{2}K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.100	m^{2}K/W
Total resistance				0.505	m^{2}K/W
Calculated U-value				**1.978**	**W/m^{2}K**
Element 4	Insulation	0.01	0.04		
Total resistance					
Calculated U-value				**1.324**	**W/m^{2}K**
Element 4	Insulation	0.025	0.04		
Total resistance					
Calculated U-value				**0.885**	**W/m^{2}K**

Table 43. Iterations for wall type Franka 800 from 800 m2 reference building office.

800 m^2	**F_800**				
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.06	m^2K/W
Element 1		0	0.18	0.000	m^2K/W
Element 2		0.8	1.1	0.727	m^2K/W
Air gap resistance	Air gap	0.05	0.18	0.18	m^2K/W
Element 3		0	0.04	0.000	m^2K/W
Element 4	Insulation	0.01	0.055	0.182	m^2K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.1	m^2K/W
Element 5	Bond stone	0.85	1.1	0.773	m^2K/W
Resistance R1				1.249	m^2K/W
Resistance R2				1.115	m^2K/W
Resistance Rupper				1.234	m^2K/W
Resistance Rlower				1.208	m^2K/W
Total resistance				1.221	m^2K/W
Calculated U-value (with bond stone)				**0.819**	**W/m^2K**
Element 4	Insulation	0.01	0.04		
Total resistance					
Calculated U-value				**0.688**	**W/m^2K**
Element 4	Insulation	0.025	0.04		
Total resistance					
Calculated U-value				**0.557**	**W/m^2K**

Table 44. Iterations for wall type Franka 900 from 800 m2 reference building office.

800 m^2	**F_900**				
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.06	m^{2}K/W
Element 1		0.01	0.055	0.182	m^{2}K/W
Element 2		0.9	1.1	0.818	m^{2}K/W
Air gap resistance	Air gap	0.05	0.18	0.18	m^{2}K/W
Element 3		0	0.04	0.000	m^{2}K/W
Element 4	Insulation	0.006	0.18	0.033	m^{2}K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.1	m^{2}K/W
Element 5	Bond stone	0.95	1.1	0.864	m^{2}K/W
Resistance R1				1.373	m^{2}K/W
Resistance R2				1.239	m^{2}K/W
Resistance Rupper				1.359	m^{2}K/W
Resistance Rlower				1.332	m^{2}K/W
Total resistance				1.345	m^{2}K/W
Calculated U-value (with bond stone)				**0.743**	**W/m^{2}K**
Element 4	Insulation	0.01	0.04		
Total resistance					
Calculated U-value				**0.633**	**W/m^{2}K**
Element 4	Insulation	0.025	0.04		
Total resistance					
Calculated U-value				**0.520**	**W/m^{2}K**

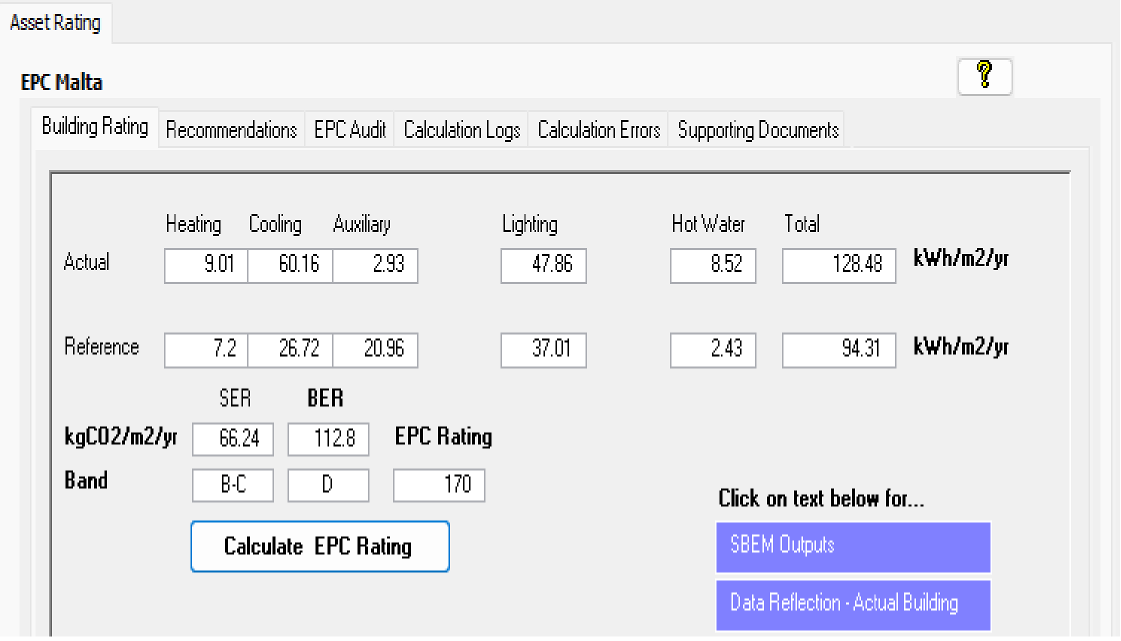


	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.2	60.71	2.93	47.86	8.52	129.22	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	
kgCO2/m2/yr	66.24	113.45	EPC Rating
Band	B-C	D	171

Click on text below for...

Figure 90. EPC Rating results for walls in 800 m2 Reference Building after applying insulation with 0.01 thickness, SBEM-mt.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.01	60.16	2.93	47.86	8.52	128.48	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	
kgCO2/m2/yr	66.24	112.8	EPC Rating
Band	B-C	D	170

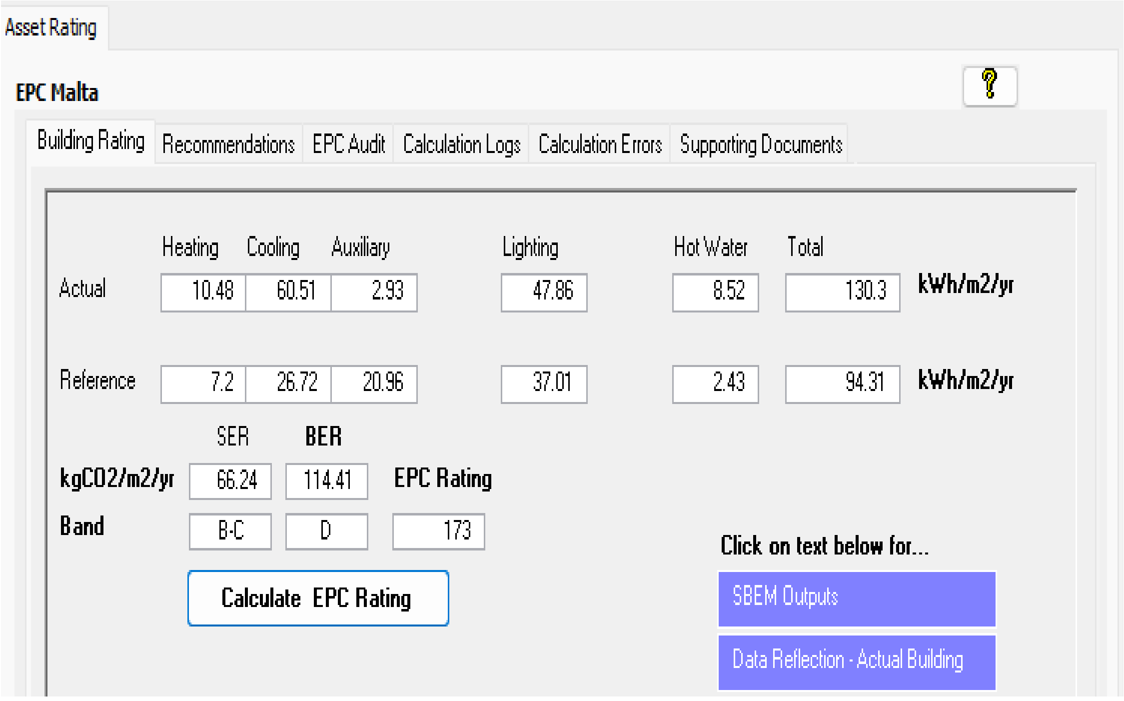
Click on text below for...

Figure 91. EPC Rating results for walls in 800 m2 Reference Building after applying insulation with 0.025 thickness, SBEM-mt.

The following table, Table 45, shows the results obtained when simulating with roof insulation, Figures 92 and 93.

Table 45. Iterations for roof from 800 m2 reference building office.

800 m^2					
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.040	m^{2}K/W
Element 1		0.004	0.23	0.017	m^{2}K/W
Element 2		0.08	0.41	0.195	m^{2}K/W
Element 3		0.08	0.8	0.100	m^{2}K/W
Element 4		0.15	2.5	0.060	m^{2}K/W
Element 5		0.012	0.04	0.300	m^{2}K/W
Element 6	Insulation	0.04	0.035	1.143	m^{2}K/W
Air gap resistance	Air gap	x	x	0.180	m^{2}K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.140	m^{2}K/W
Total resistance				2.175	m^{2}K/W
Calculated U-value				**0.460**	**W/m^{2}K**
Element 6	Insulation	0.07	0.035	2.000	m^{2}K/W
Calculated U-value				**0.330**	**W/m^{2}K**
Element 6	Insulation	0.1	0.035	2.857	m^{2}K/W
Calculated U-value				**0.257**	**W/m^{2}K**



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	10.48	60.51	2.93	47.86	8.52	130.3	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.24	114.41	
Band	B-C	D	173

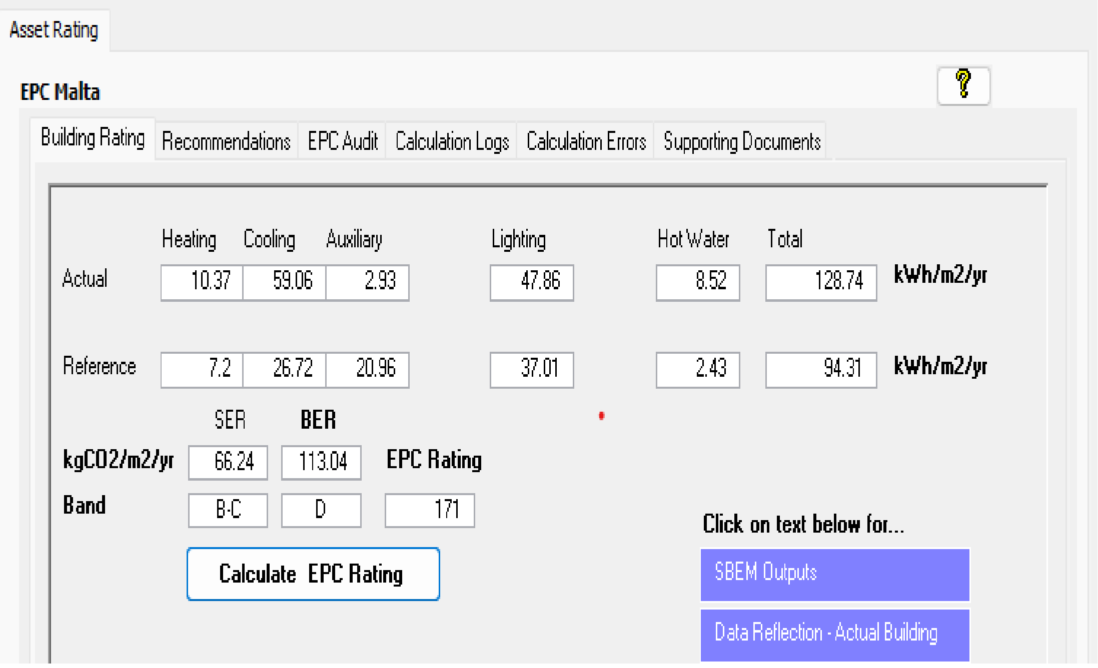
Figure 92. EPC Rating results for roof in 800 m2 Reference Building after applying insulation with 0.07 thickness, SBEM-mt.

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.29	60.1	2.93	47.86	8.52	128.71	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.24	113	
Band	B-C	D	171

Figure 93. EPC Rating results for roof in 800 m2 Reference Building after applying insulation with 0.01 thickness, SBEM-mt.

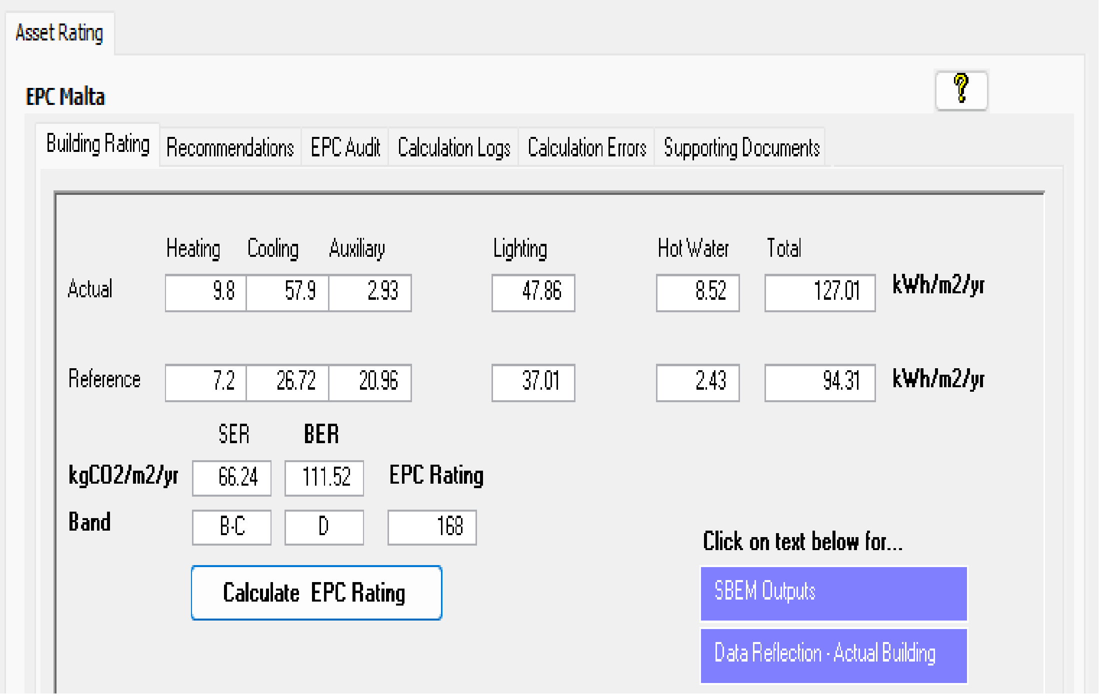
The results obtained in SBEM-mt after modifying the type of glazing and frame of the reference office are shown below, Figure 94 and Figure 95.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	10.37	59.06	2.93	47.86	8.52	128.74	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.24	113.04	
Band	B-C	D	171

Figure 94. EPC Rating results for glazing type 4-6-4 uncoated glass and frame type metal frame no thermal break thermally improved spacer in 800 m2 Reference Building, SBEM-mt.

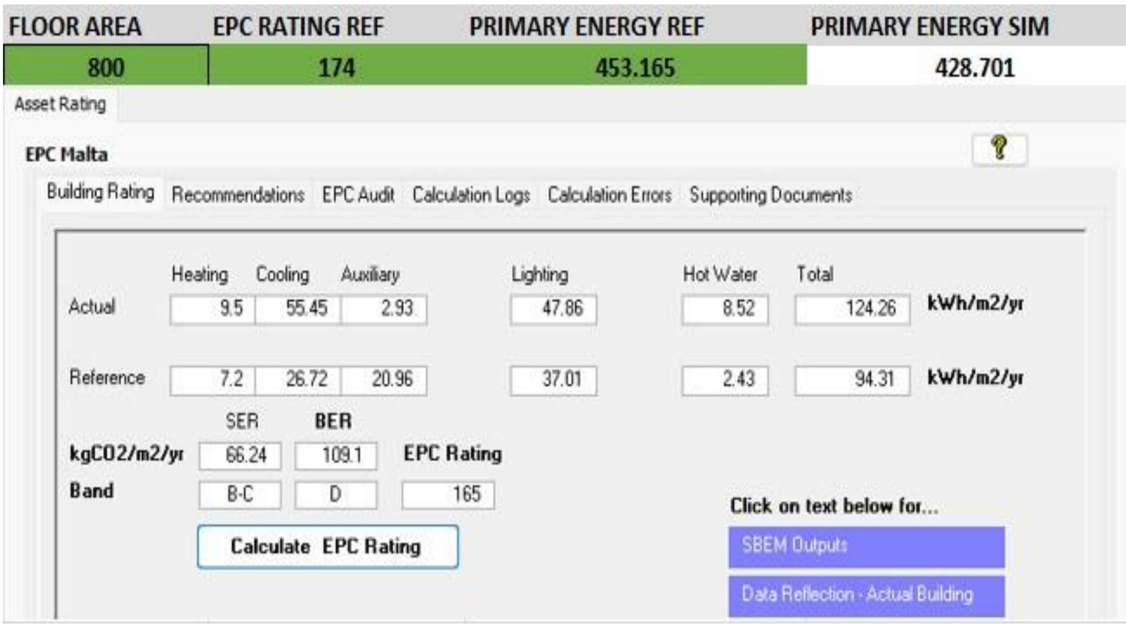


	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.8	57.9	2.93	47.86	8.52	127.01	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.24	111.52	
Band	B-C	D	168

Figure 95. EPC Rating results for glazing type 4-6-4 low-e air-filled and frame type metal frame thermal break thermally improved spacer in 800 m2 Reference Building, SBEM-mt.

In Figure 96, the combined results of all optimum building envelope energy efficiency measures are shown, where "EPC rating ref" and "primary energy ref" are the reference values and "primary energy sim" as well as the detailed results after applying the measures and simulating.



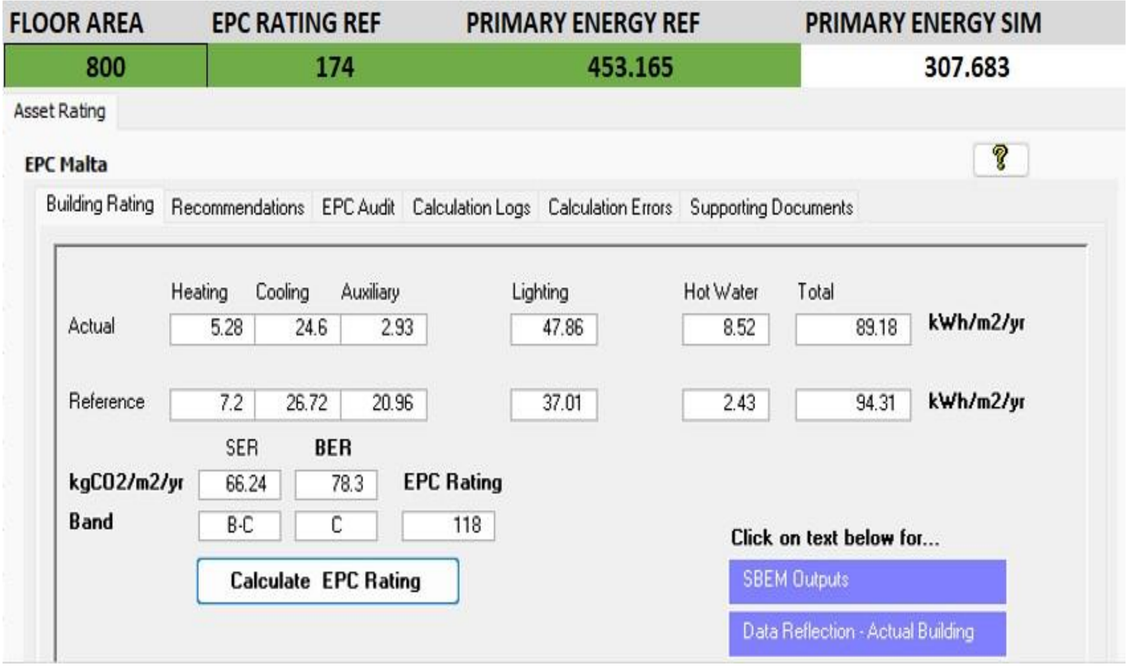
FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
800	174	453.165	428.701

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	9.5	55.45	2.93	47.86	8.52	124.26	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.24	109.1	
Band	B-C	D	165

Figure 96. EPC Rating results for walls, roof and glazing in 800 m2 Reference Building after applying the best percentage improvements measures, SBEM-mt.

Figure 97 below shows the results of simulating improving the energy efficiency of air conditioners for both heating and cooling.



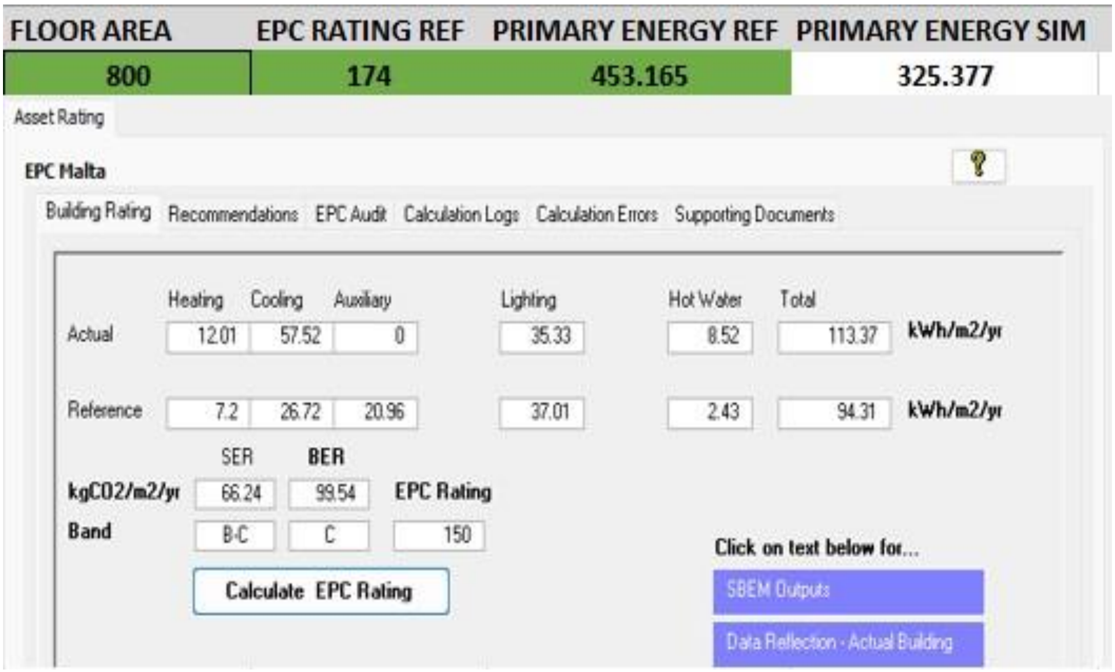
FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
800	174	453.165	307.683

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	5.28	24.6	2.93	47.86	8.52	89.18	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.24	78.3	
Band	B-C	C	118

Figure 97. EPC Rating results for air conditioner in 800 m2 Reference Building, SBEM-mt.

The results of simulating improving the energy efficiency for artificial lighting are shown in Figure 98 below.



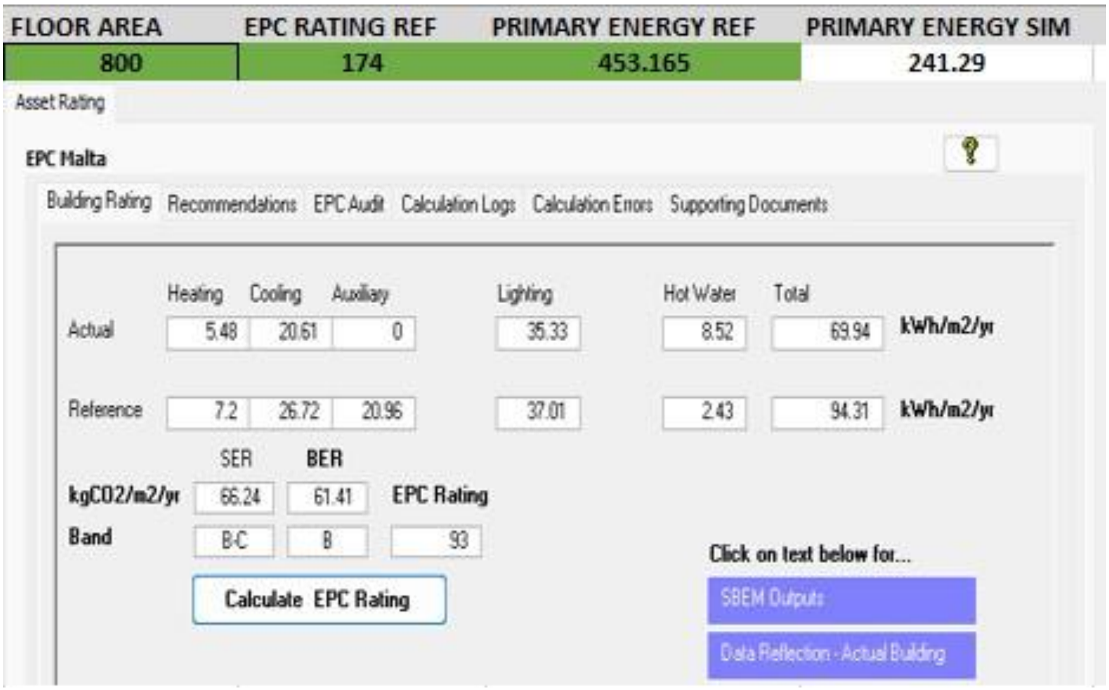
FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
800	174	453.165	325.377

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	12.01	57.52	0	35.33	8.52	113.37	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.24	99.54	
Band	B-C	C	150

Figure 98. EPC Rating results for lighting in 800 m2 Reference Building, SBEM-mt.

Figure 99 below shows the combined results after applying the optimum insulation measures, increased energy efficiency of the AC and lighting. It can also be seen how the primary energy and EPC rating of the office is significantly improved.



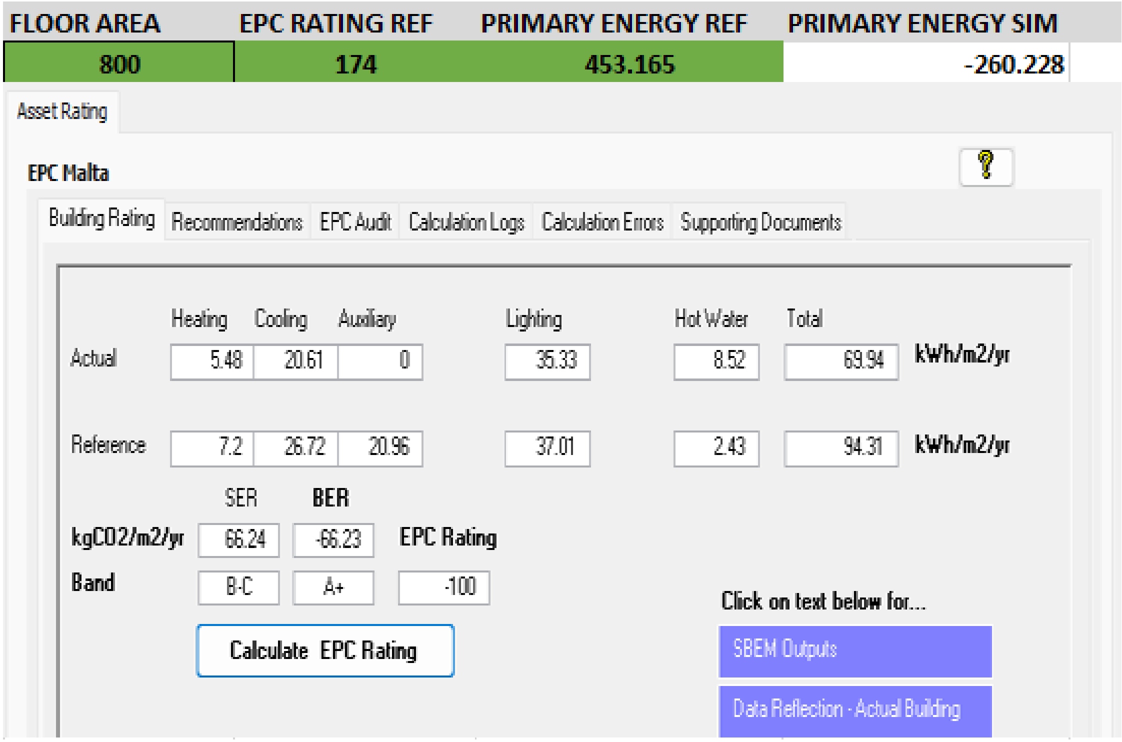
FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
800	174	453.165	241.29

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	5.48	20.61	0	35.33	8.52	69.94	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.24	61.41	
Band	B-C	B	93

Figure 99. EPC Rating results for all measures less PV systems in 382 m2 Reference Building, SBEM-mt.

Figure 100 shows how after applying all the measures to improve the energy efficiency of the office and subsequently adding an 85 kWp photovoltaic system very promising results were achieved. The EPC rating improves from 174 (class C) to -100 (class A+) pointing that not only the construction has become energetically efficient but also produces more green energy that it consumes.



FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
800	174	453.165	-260.228

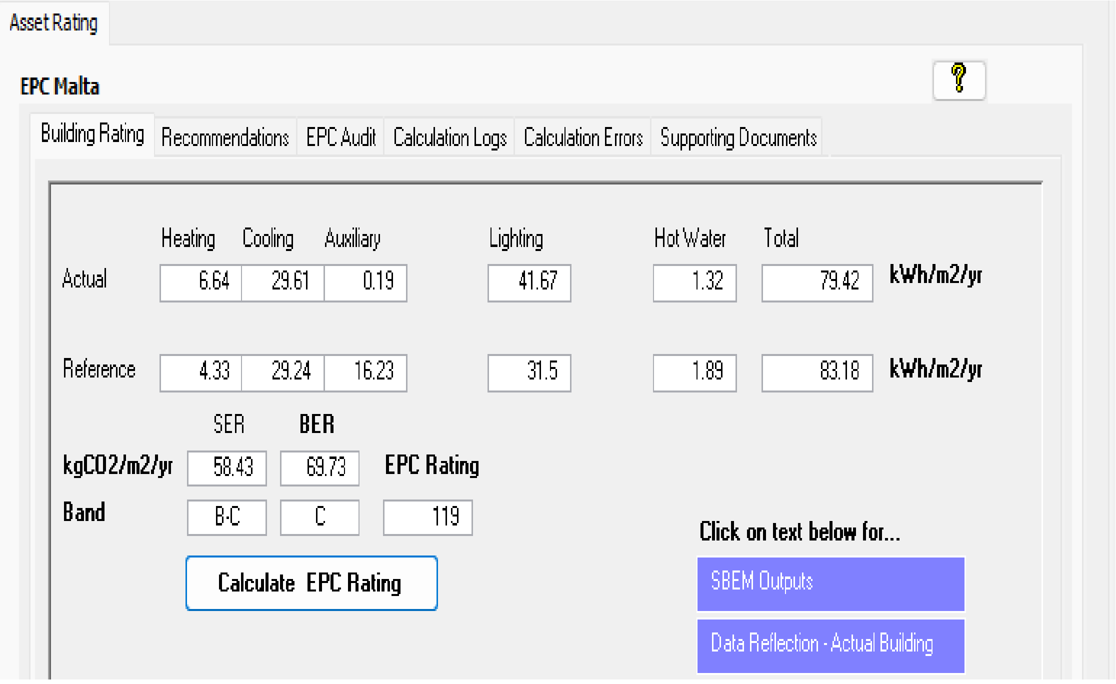
	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	5.48	20.61	0	35.33	8.52	69.94	kWh/m2/yr
Reference	7.2	26.72	20.96	37.01	2.43	94.31	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	66.24	-66.23	
Band	B-C	A+	-100

Figure 100. EPC Rating results for all measures and PV systems in 382 m2 Reference Building, SBEM-mt.

4.2.4 RESULTS FOR 4199 m^2 REFERENCE BUILDING.

Figure 101, shows the results obtained (EPC Rating) of the walls after simulating only with the reference building without applying any energy efficiency measures.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	6.64	29.61	0.19	41.67	1.32	79.42	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	69.73	
Band	B-C	C	119

Figure 101. EPC Rating results for walls in 4199 m2 Reference Building without energy efficiency measures, SBEM-mt.

After applying insulations to the different walls (named as Franka 30, Franka 460 and Franka Single), as detailed in Table 46, Table 47 and Table 48 the results obtained by simulating in SBEM-mt for the EPC Rating are shown below in Figure 102 and Figure 103 for two different levels of insulation thickness.

Table 46. Iterations for wall type Franka 30 from 4199 m2 reference building office.

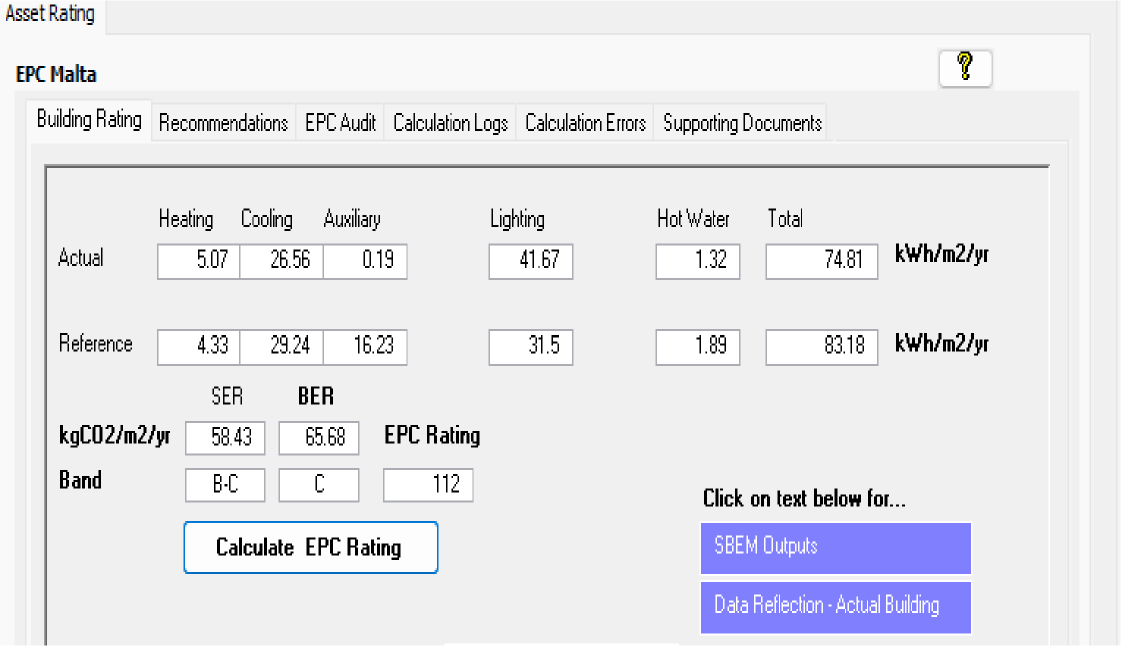
4199 m^2	**franka_30cm**				
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.060	m^{2}K/W
Element 1		0	0.18	0.000	m^{2}K/W
Element 2		0.3	1.1	0.273	m^{2}K/W
Element 3		0	0.18	0.000	m^{2}K/W
Element 4	Insulation	0	2.3	0.000	m^{2}K/W
Element 5		0	0.18	0.000	m^{2}K/W
Element 6		0	0	0.000	m^{2}K/W
Air gap resistance	Air gap	x	x	0.000	m^{2}K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.100	m^{2}K/W
Total resistance				0.433	m^{2}K/W
Calculated U-value				**2.311**	**W/m^2 K**
Element 4	Insulation	0.01	0.04	0.250	m^{2}K/W
Total resistance				0.683	m^{2}K/W
Calculated U-value				**1.465**	**W/m^2 K**
Element 4	Insulation	0.025	0.04	0.625	m^{2}K/W
Total resistance				1.058	m^{2}K/W
Calculated U-value				**0.945**	**W/m^2 K**

Table 47. Iterations for wall type Franka 46 from 4199 m2 reference building office.

4199 m^2	**franka_46cm**				
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.060	m^{2}K/W
Element 1		0	0.18	0.000	m^{2}K/W
Element 2		0.46	1.1	0.418	m^{2}K/W
Element 3		0	0.18	0.000	m^{2}K/W
Element 4	Insulation	0	0.04	0.000	m^{2}K/W
Element 5		0	0.18	0.000	m^{2}K/W
Element 6		0	0	0.000	m^{2}K/W
Air gap resistance	Air gap	x	x	0.000	m^{2}K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.100	m^{2}K/W
Total resistance				0.578	m^{2}K/W
Calculated U-value				**1.730**	**W/m^{2}K**
Element 4	Insulation	0.01	0.04		
Total resistance					
Calculated U-value				**1.207**	**W/m^{2}K**
Element 4	Insulation	0.025	0.04		
Total resistance					
Calculated U-value				**0.831**	**W/m^{2}K**

Table 48. Iterations for wall type Franka Single from 4199 m2 reference building office.

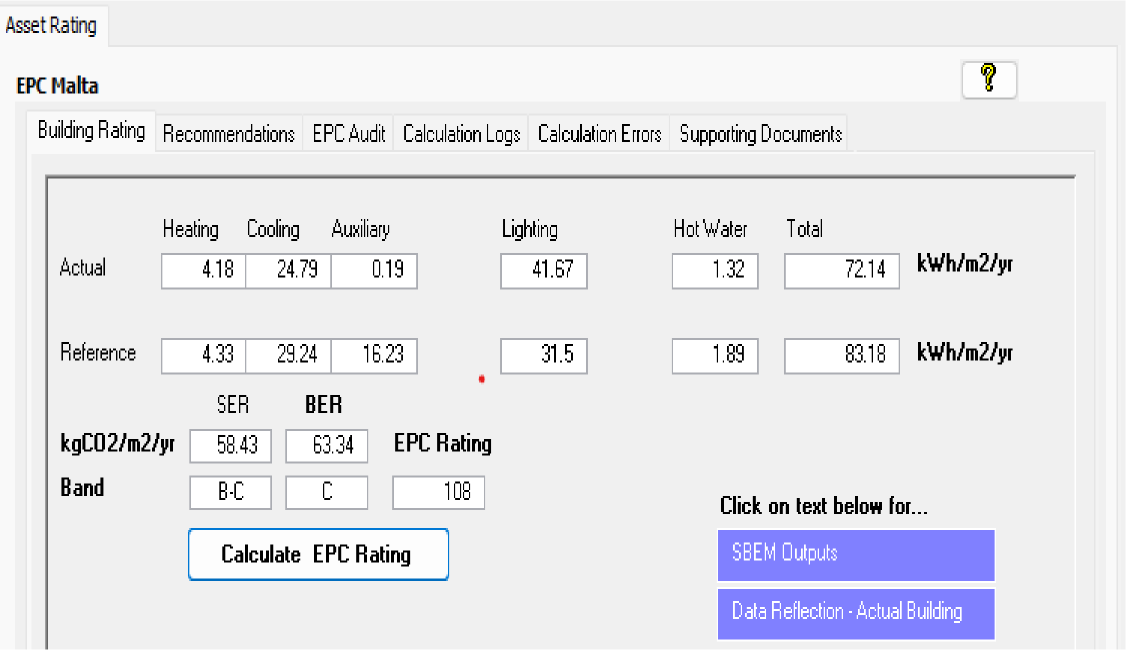
4199 m^2	**franka_single**				
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.060	m^{2}K/W
Element 1		0	0.18	0.000	m^{2}K/W
Element 2		0.23	1.1	0.209	m^{2}K/W
Element 3		0	0.18	0.000	m^{2}K/W
Element 4	Insulation	0	0.04	0.000	m^{2}K/W
Element 5		0	0.18	0.000	m^{2}K/W
Element 6		0	0	0.000	m^{2}K/W
Air gap resistance	Air gap	x	x	0.000	m^{2}K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.100	m^{2}K/W
Total resistance				0.369	m^{2}K/W
Calculated U-value				**2.709**	**W/m^{2}K**
Element 4	Insulation	0.01	0.04		
Total resistance					
Calculated U-value				**1.615**	**W/m^{2}K**
Element 4	Insulation	0.025	0.04		
Total resistance					
Calculated U-value				**1.006**	**W/m^{2}K**



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	5.07	26.56	0.19	41.67	1.32	74.81	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	65.68	
Band	B-C	C	112

Figure 102. EPC Rating results for walls in 4199 m2 Reference Building after applying insulation with 0.01 thickness, SBEM-mt.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	4.18	24.79	0.19	41.67	1.32	72.14	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

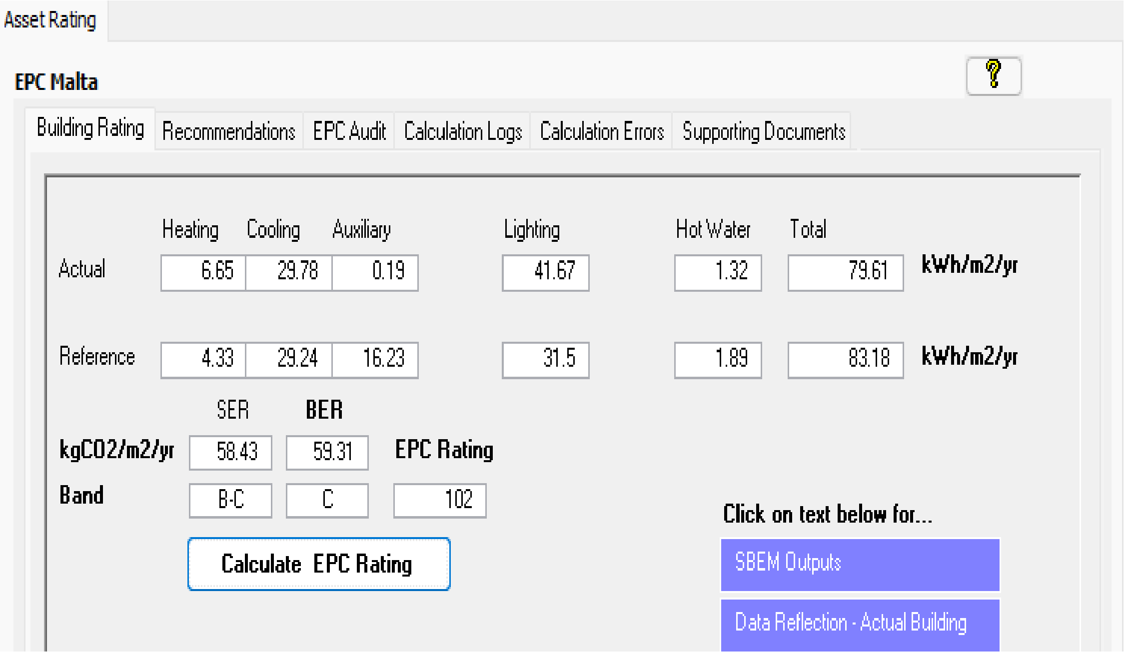
	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	63.34	
Band	B-C	C	108

Figure 103. EPC Rating results for walls in 4199 m2 Reference Building after applying insulation with 0.025 thickness, SBEM-mt.

Table 49 shows the results obtained when simulating with roof insulation, Figures 104 and 105.

Table 49. Iterations for roof from 4199m2 reference building office.

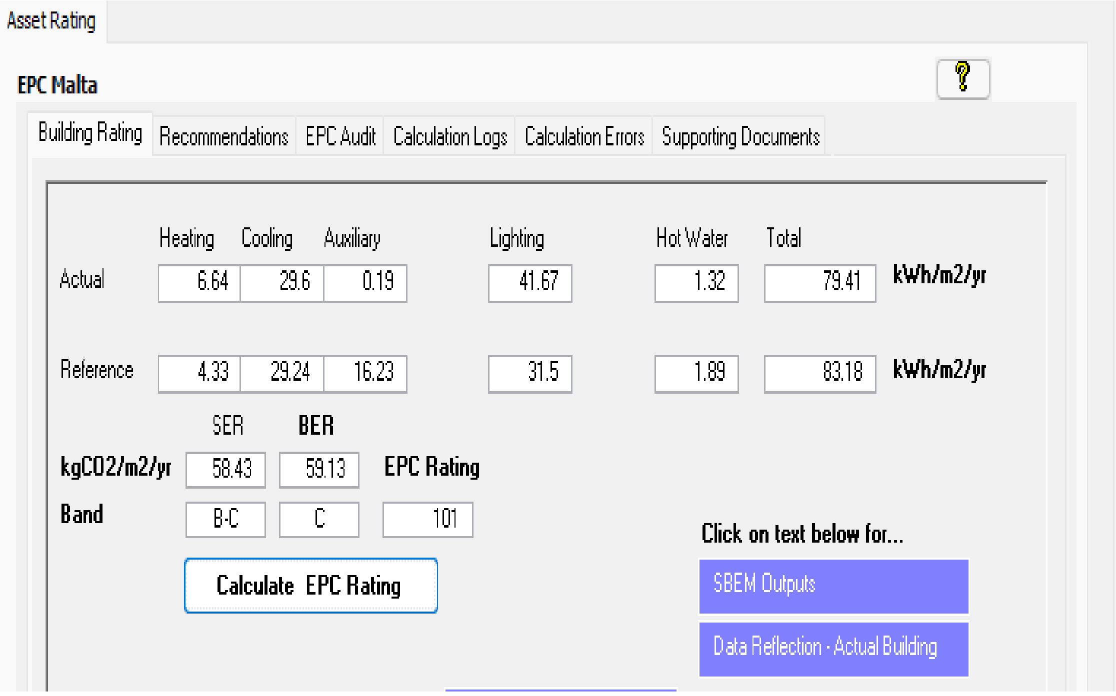
4199					
	Description	Thickness, x	conductivity, k		
Rse	External surface resistance	[redacted]	[redacted]	0.040	m^2K/W
Element 1		0.004	0.23	0.017	m^2K/W
Element 2		0.08	0.41	0.195	m^2K/W
Element 3		0.08	0.8	0.100	m^2K/W
Element 4		0.15	2.5	0.060	m^2K/W
Element 5		0.012	0.04	0.300	m^2K/W
Element 6	Insulation	0.04	0.035	1.143	m^2K/W
Air gap resistance	Air gap	x	x	0.180	m^2K/W
Rsi	Internal surface resistance	[redacted]	[redacted]	0.140	m^2K/W
Total resistance				2.175	m^2K/W
Calculated U-value				**0.460**	**W/m^2K**
Element 6	Insulation	0.07	0.035	2.000	m^2K/W
Calculated U-value				**0.330**	**W/m^2K**
Element 6	Insulation	0.1	0.035	2.857	m^2K/W
Calculated U-value				**0.257**	**W/m^2K**



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	6.65	29.78	0.19	41.67	1.32	79.61	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	59.31	
Band	B-C	C	102

Figure 104. EPC Rating results for roof in 4199 m2 Reference Building after applying insulation with 0.07 thickness, SBEM-mt.

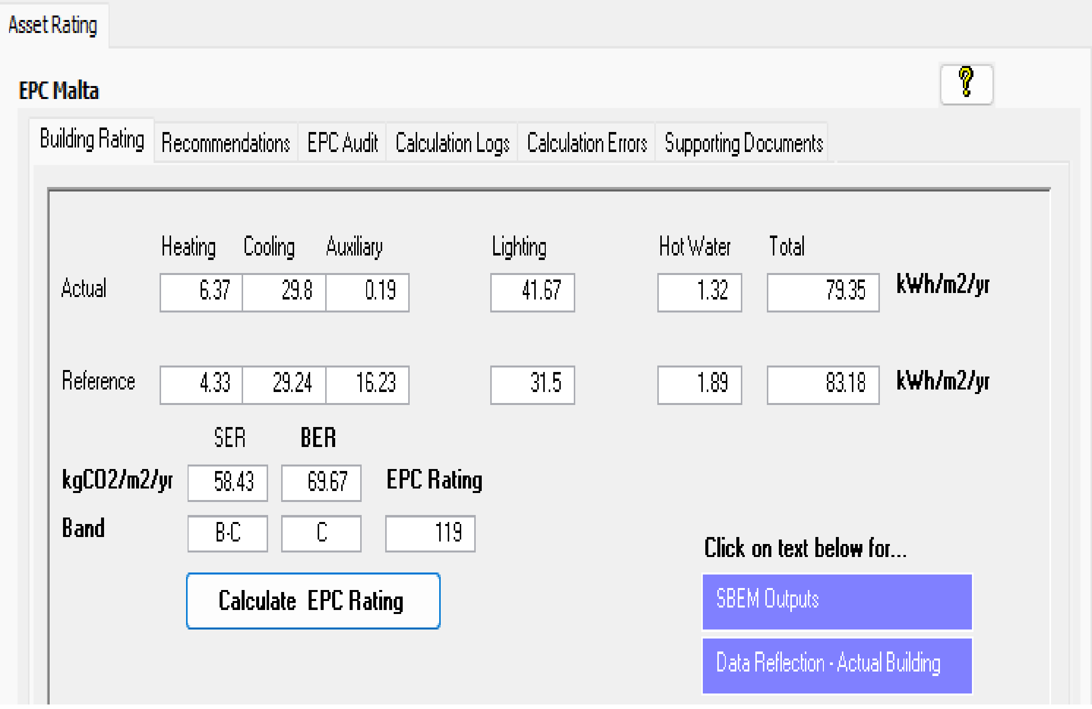


	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	6.64	29.6	0.19	41.67	1.32	79.41	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	59.13	
Band	B-C	C	101

Figure 105. EPC Rating results for roof in 4199 m2 Reference Building after applying insulation with 0.01 thickness, SBEM-mt.

The results obtained in SBEM-mt after modifying the type of glazing and frame of the reference office are shown below in Figure 106 and Figure 107.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	6.37	29.8	0.19	41.67	1.32	79.35	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	69.67	
Band	B-C	C	119

Figure 106. EPC Rating results for glazing type 4-6-4 uncoated glass and frame type metal frame no thermal break thermally improved spacer in 4199 m2 Reference Building, SBEM-mt.

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	5.94	29.52	0.19	41.67	1.32	78.63	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	69.04	
Band	B-C	C	118

Figure 107. EPC Rating results for glazing type 4-6-4 low-e air-filled and frame type metal frame thermal break thermally improved spacer in 4199 m2 Reference Building, SBEM-mt.

Figure 108 shows the combined optimum building envelope energy efficiency measures, where “EPC rating ref” and “primary energy ref” are the reference values and “primary energy sim” and the detailed results refer to the results after applying the measures and simulating.

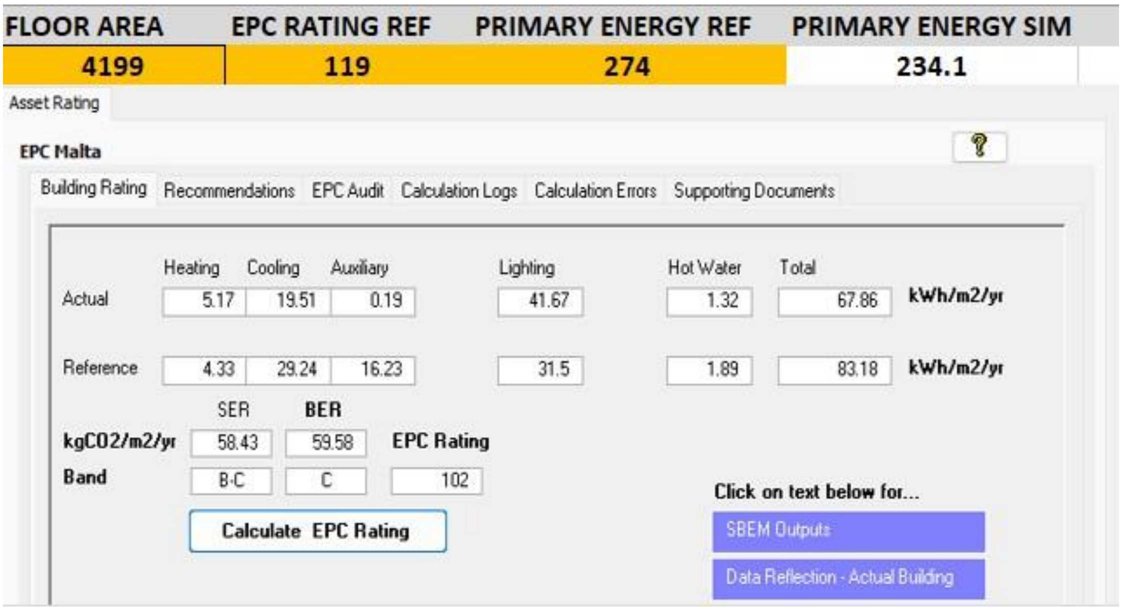
FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
4199	119	274	244.642

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	3.45	24.29	0.19	41.67	1.32	70.91	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	62.26	
Band	B-C	C	107

Figure 108. EPC Rating results for walls, roof and glazing in 4199 m2 Reference Building after applying the best percentage improvements measures, SBEM-mt.

Figure 109 below shows the results of simulating improved air conditioners for both heating and cooling.



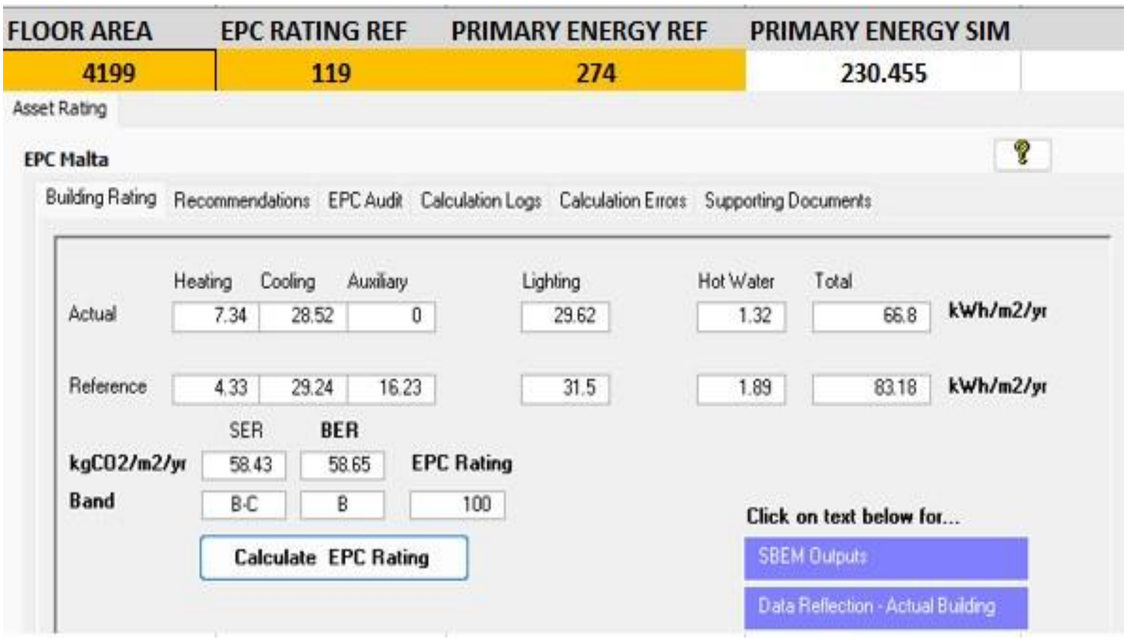
FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
4199	119	274	234.1

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	5.17	19.51	0.19	41.67	1.32	67.86	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	59.58	
Band	B-C	C	102

Figure 109. EPC Rating results for air conditioner in 4199 m2 Reference Building, SBEM-mt.

The results of simulating improved artificial lighting are shown in Figure 110 below.



FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
4199	119	274	230.455

Asset Rating

EPC Malta

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	7.34	28.52	0	29.62	1.32	66.8	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	58.65	
Band	B-C	B	100

Figure 110. EPC Rating results for lighting in 4199 m2 Reference Building, SBEM-mt.

Figure 111 below shows the results after applying the combined building envelope energy efficiency measures, increased energy efficiency of the AC and lighting. It can also be seen how the primary energy and EPC rating of the office is significantly improved.

FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
4199	119	274	167.949

Asset Rating

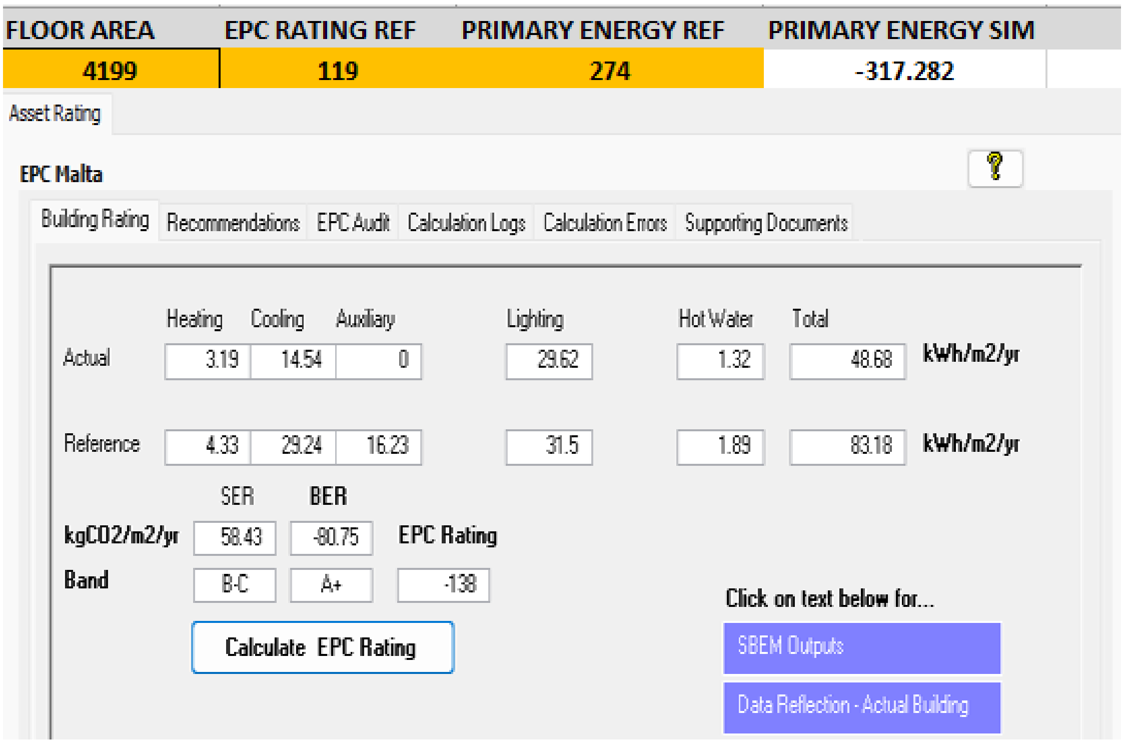
EPC Malta

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	3.19	14.54	0	29.62	1.32	48.68	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	42.74	
Band	B-C	B	73

Figure 111. EPC Rating results for all measures less PV systems in 4199 m2 Reference Building, SBEM-mt.

Figure 112 shows how after applying all the measures to improve the energy efficiency of the office and subsequently adding 480 kWp photovoltaic system very promising results were achieved. The EPC rating has turned up from 119 (class C) to -138 (class A+) pointing that not only the construction has become energetically efficient but also produces more green energy than it consumes.



FLOOR AREA	EPC RATING REF	PRIMARY ENERGY REF	PRIMARY ENERGY SIM
4199	119	274	-317.282

	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	3.19	14.54	0	29.62	1.32	48.68	kWh/m2/yr
Reference	4.33	29.24	16.23	31.5	1.89	83.18	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	58.43	-80.75	
Band	B-C	A+	-138

Figure 112. EPC Rating results for all measures and PV systems in 4199 m2 Reference Building, SBEM-mt.

4.3 SUMMARY OF RESULTS

In this new section, the effect of the measures on each reference office will be evaluated by means of histogram plots based on the primary energy values obtained after simulations with the SBEM-mt software.

4.3.1 REFERENCE OFFICE 104m^2

Figure 113 shows the histogram with the results as a function of primary energy for the first office, 104 m^2 floor area.

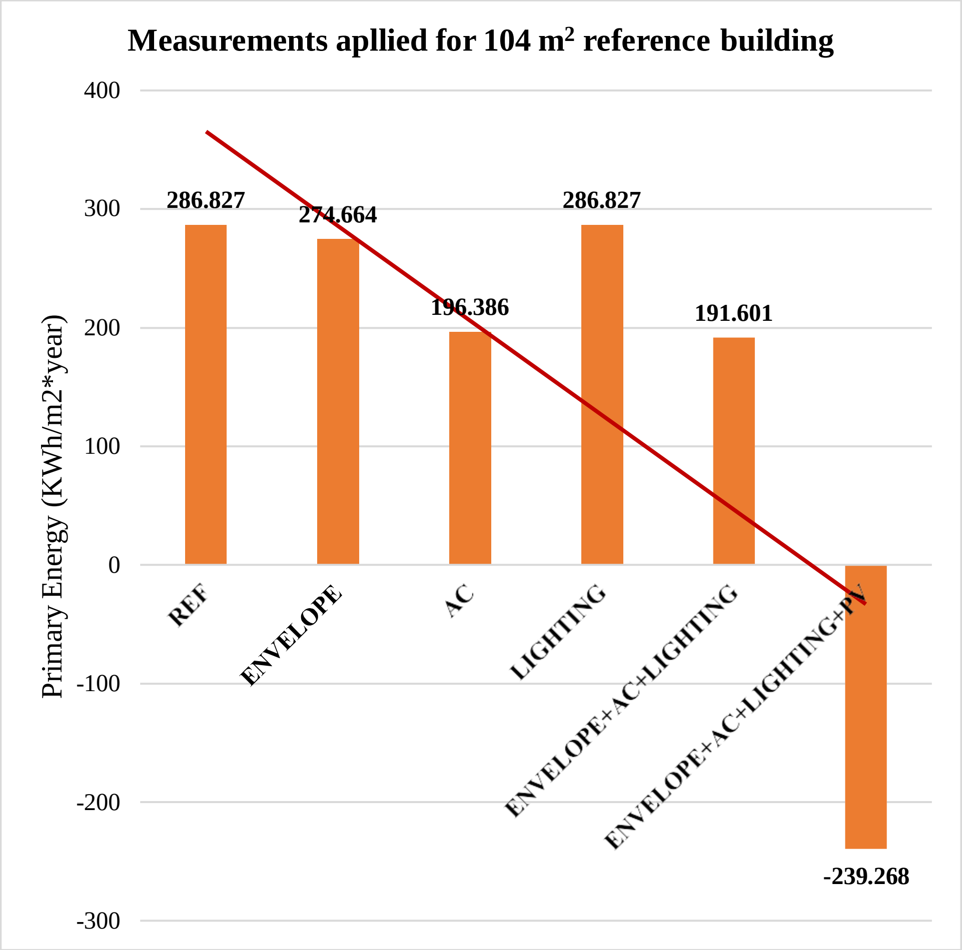


Figure 113. Histogram of the results of the SBEM-mt simulations for the 104m^2 office.

4.3.2 REFERENCE OFFICE 382 m^2

Figure 114 shows the histogram with the results as a function of primary energy for the second office, 382 m^2 floor area.

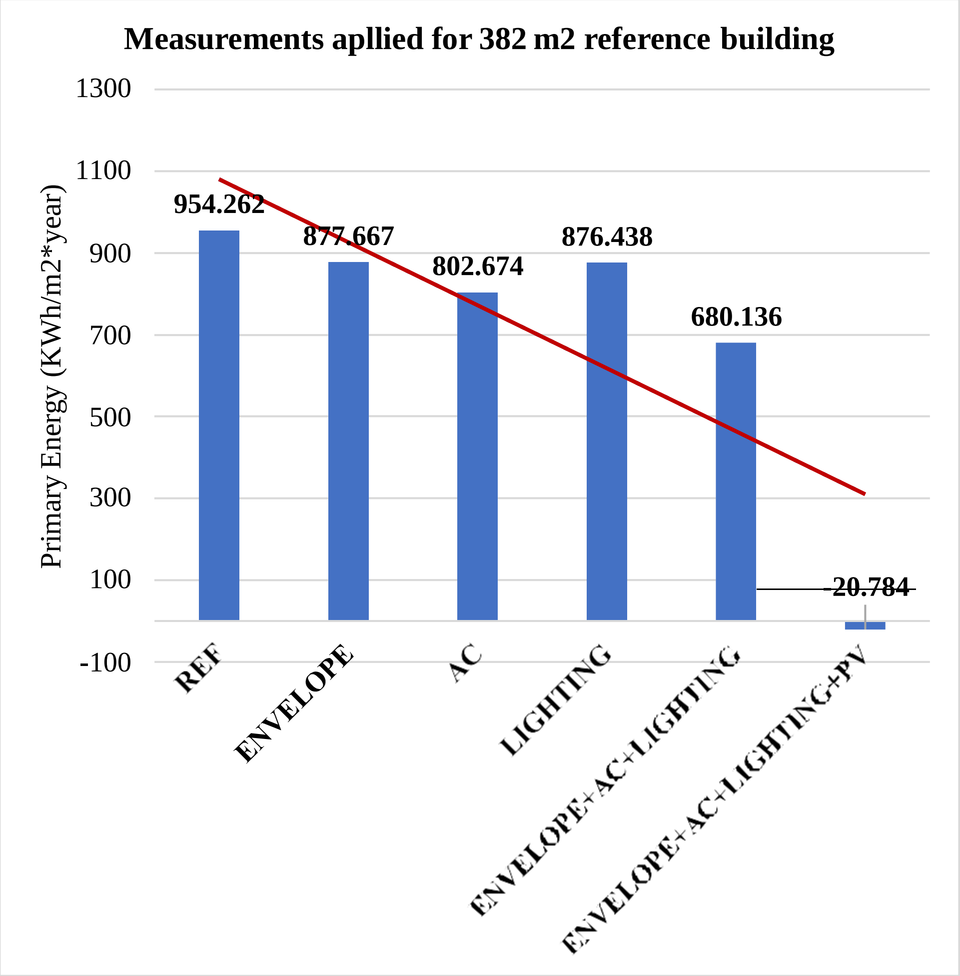


Figure 114. Histogram of the results of the SBEM-mt simulations for the 382 m^2 office.

4.3.3 REFERENCE OFFICE 800m^2

Figure 115 shows the histogram with the results as a function of primary energy for the third office, 800 m^2 floor area.

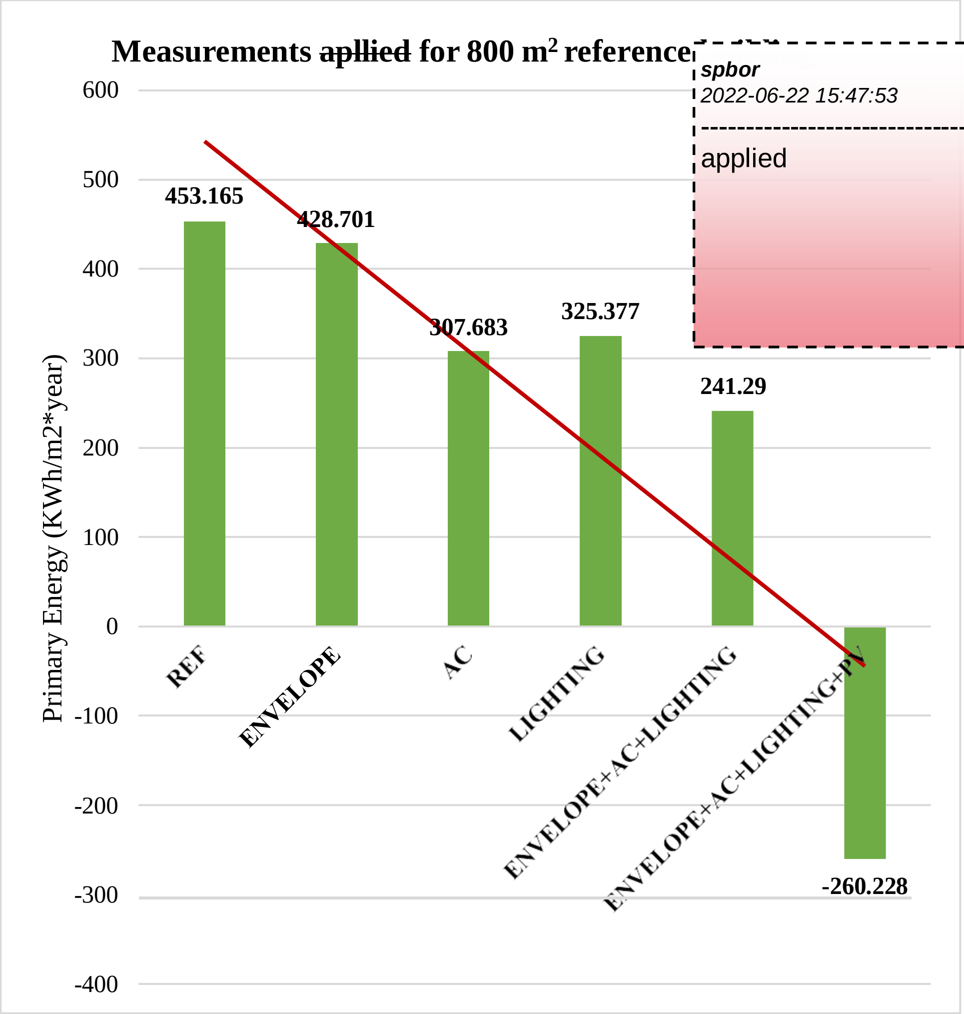


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Figure 115. Histogram of the results of the SBEM-mt simulations for the 104m^2 office.

4.3.4 REFERENCE OFFICE 4199m^2

Figure 116 shows the histogram with the results as a function of primary energy for the fourth office, 4199 m^2 floor area.

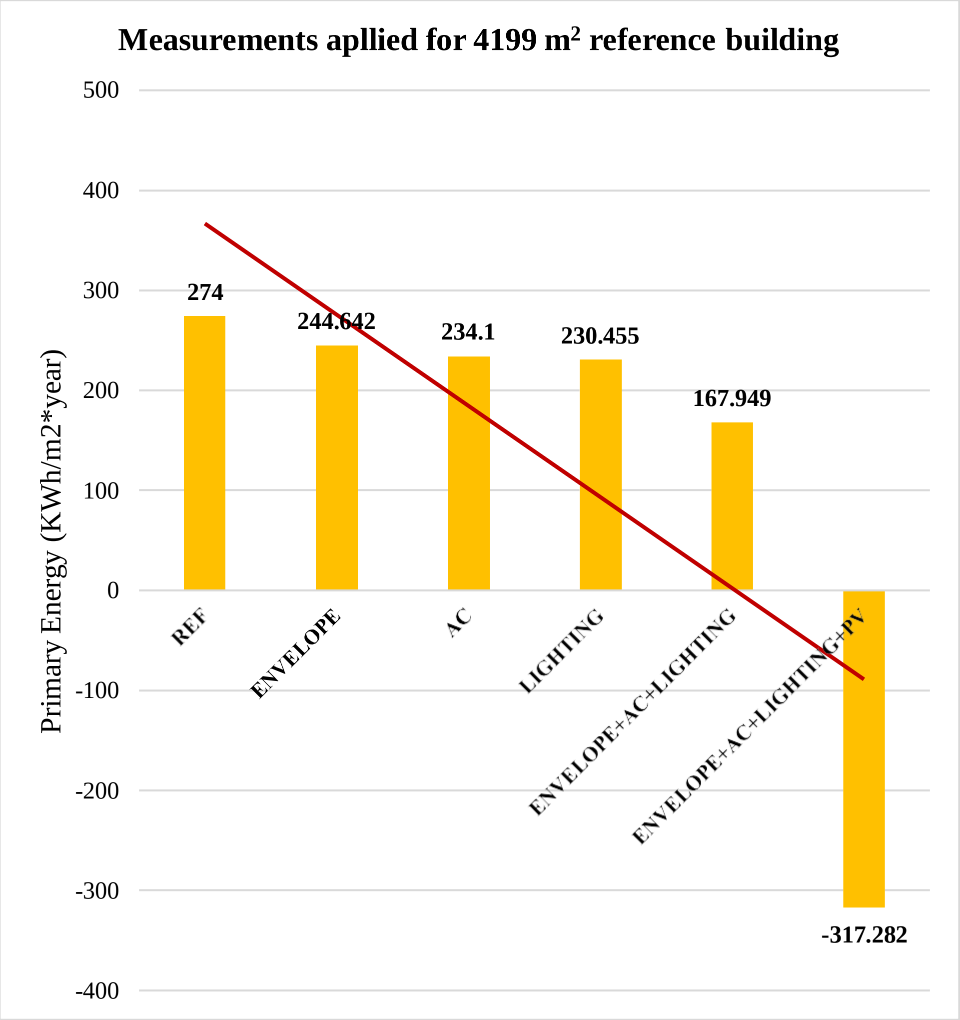
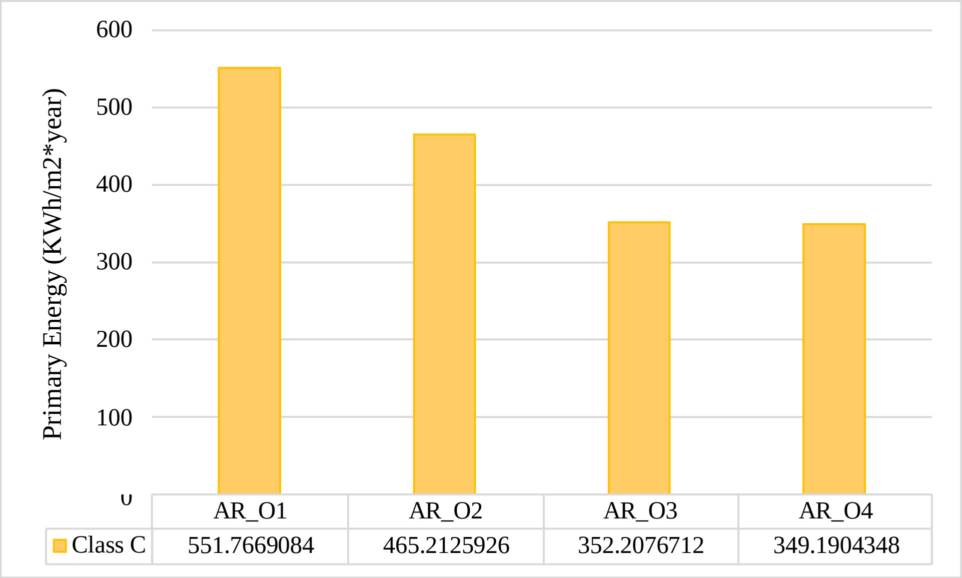


Figure 116. Histogram of the results of the SBEM-mt simulations for the 104m^2 office.

4.3.5 ANALYSIS OF HISTOGRAMS

First of all, as can be seen in Table 50 for the different offices the primary energy rating of a specific energy class (e.g. Class C) is different, with smaller area offices having higher values. This behaviour justifies the proposed clustering of offices based on their floor area.

Table 50. Average primary energy required for Class C depending on the asset rating office floor area.



The fact that the slope of all histograms of Figures 113, 114, 115, 116 is decreasing shows in a clear and simple way how the applied energy efficiency improvement measures have satisfactory results on the primary energy, and consequently the EPC energy rating, of the analysed offices.

Regarding the measures related to the building envelope, as shown in Table 51, the office with floor area 4199 m2 has the highest potential for improvement.

Table 51. Percentage of improving with envelope measures.

Floor Area	**Percentage of improving with Envelope Measures**
4199	10.715%
800	5.398%
382	8.027%
104	4.241%

Of all the measures applied (excluding PV), it can be seen in Table 52 how the control of the performance of the AC systems alone has a greater impact on the EPC rating, greatly reducing the building's consumption.

Table 52. Percentage of improving with optimum COPs values for AC systems.

Floor Area	Percentage of improving with optimum COPs values for AC systems.
4199	14.562%
800	32.104%
382	15.885%
104	31.532%

In the case of lighting control shown in Table 53, the percentages are also high showing that it is an important factor in its own right when assessing the energy efficiency of a building and as an improvement. The fact that the office with the smallest floor area has no improvement is because it already had the optimal fluorescent lamps applied.

Table 53. Percentage of improving with lighting measures.

Floor Area	Percentage of improving with Lighting Measures.
4199	15.892%
800	28.199%
382	8.155%
104	0.000%

As can be seen below in Table 54, all the offices can achieve higher energy efficiency without PV but specially the office with floor area 800 m2 has the best potential of improving.

Table 54. Percentage of improving without PV systems.

Floor Area	Percentage of improving without PV
4199	38.705%
800	46.754%
382	28.726%
104	33.200%

Assuming that only one of these three measures can be implemented, as can be seen in Tables 50, 51 and 52, the improvement of air-conditioning systems (heating and cooling) would score first as it provides higher savings than the other measures alone.

For all cases, PV has the best chance to make the offices zero energy.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This dissertation has produced a number of important results concerning the database of offices EPCs in Malta. First, the overall office energy rating of the whole stock was mostly around Energy Classes C and D, which meant that there is potential for improvement for all office clusters.

Offices were divided into four clusters according to the total floor area as follows:

O1: 0 m^2<Floor area≤250 m^2

O2: 250 m^2<Floor area≤500m^2

O3: 500 m^2<Floor area≤1500 m^2

O4: 1500 m^2<Floor area

In addition, each of these clusters was further subdivided into two other groups depending on whether they belonged to offices already built (asset rating) or to be built (design rating).

A problem was encountered when it was observed that a higher number of the expected buildings listed in the database stock behaved statistically as outliers for their defined category. This may be because they are either outliers in which case the method of entering and cataloguing the sample (offices) in the database would have to be revised, or that some were not outliers but the floor area bands to differentiate between categories or clusters are not sufficiently narrow for all samples to fit within so that new intervals would have to be recalculated and more or less clusters would have to be created depending on the floor area.

Secondly, when comparing the Asset Rating offices to the Design Rating offices for the four categories defined above, it was found that the median values for the Design Rating offices were slightly smaller than the Asset Rating and their energy performance was better.

Third, the use of four representative existing office files in SBEM-mt to simulate different energy efficiency measures for the building envelope, the building energy systems and solar photovoltaics yielded very positive results, with all offices achieving an A+ energy rating, when combined energy efficiency measures and solar photovoltaics are implemented. The most surprising result was that the office in the 800 m² reference building, which started out completely inefficient, ended up with the best possible EPC rating. The study has only focused on improving the existing offices rather than analysing the new office designs, because the number of existing offices far exceed the construction of new ones and would need to be given a priority.

Fourth, although building envelope improvements had potentially the smallest contribution, it is not justified that these are ignored, because without them the overall energy rating would not be as efficient and also because the principle of the “Energy Efficiency First” is to be respected. In other words, it is important to improve the indoor comfort levels through insulation and shading before applying renewable energy to the office building.

Fifth, when comparing the potential of improving the energy rating for building energy systems, it was demonstrated that improvement in air conditioning system performance has the highest impact followed by lighting.

5.2 RECOMMENDATIONS

First, to avoid the possibility of entering erroneous data or outliers in the databases to be used for the statistical studies of EPCs, the data entry process should be strengthened with an initial analysis of the offices to verify if the data entered are correct. At a later stage, the possibility of studying offices with different floor area bands, smaller or larger than those used in this dissertation, should be considered to verify if it favours the adaptability of the data to the clusters to which they are assigned, thus further reducing the number of outliers in the process. In other words, an optimisation exercise can be carried out to determine the best floor area limits to be introduced for the four categories, in order to fit as many EPCs as possible within the acceptable limits rather than leaving them out as outliers.

The standardisation of this methodology is also a necessary point for both Malta and the European Union so that information on the results obtained can be shared on the basis of a common methodology to favour the advancement of energy efficiency in buildings, making this process faster and less costly in terms of searching for references and information.

Although during the study the percentage of improvement and the assumption of using the cheapest option in case of no significant difference have been taken into account, later on, the purpose of this dissertation should be re-evaluated by calculating new results from an economic point of view in order to facilitate the implementation of the measures in a fully optimal way. Therefore, it is recommended to complete the study with a new study of the optimum cost of the measures applied.

In addition, the causes for the existence of some inefficient offices as was shown in Tables 24 to 27 (the worst performers in Classes D, E, F and G) must be investigated by carrying out a statistical analysis of consumption in these offices, for example by studying individual consumption in areas of interest such as lighting, heating, cooling, auxiliary and hot water consumption.

Furthermore, educating the public about EPCs should be a strength of any nation or population in the European area as sharing with the owner of a private home or business building information about how they can improve their property energy-wise, recommended measures, the benefits of these measures, consequences of not implementing these measures in the long and medium term, and supporting the individual or family financially to implement the recommended measures will potentially increase the public's knowledge about it and interest in implementing these improvements. The redesign of EPCs should also be considered, to produce a clearer, more attractive and simpler design for the customer and for the owner.

In short, as more people become aware of the existence of EPCs and their real value, easier the transition towards the proposed objectives will be.

Last but not least, any process of improving quality, performance, efficiency must be simple and continuous. The principles of continuous improvement usually used in operational processes should be applied to design a standard, transparent, modern and easy to carry out process that results in high quality analysis of EPCs and greatly boosts the transition towards efficient building and construction.

REFERENCES

[1] Nies, S. (Ed.). (2019). The european energy transition: Actors, factors, sectors. Claeys and Casteels Publishing.

[2] Ćetković, S., & Buzogány, A. (2016). Varieties of capitalism and clean energy transitions in the European Union: When renewable energy hits different economic logics. Climate Policy, 16(5), 642-657.

[3] Wierling, A., Schwanitz, V., Zeiß, J., Bout, C., Candelise, C., Gilcrease, W., & Gregg, J. (2018). Statistical Evidence on the Role of Energy Cooperatives for the Energy Transition in European Countries. Sustainability (Basel, Switzerland), 10(9), 3339.

[4] Potrč, S., Čuček, L., Martin, M., & Kravanja, Z. (2021). Sustainable renewable energy supply networks optimization – The gradual transition to a renewable energy system within the European Union by 2050. Renewable & Sustainable Energy Reviews, 146, 111186.

[5] European Commission. (2020). Energy Efficiency of Buildings, Brussels, https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-feb-17_es, accessed on 20th Feb 2022.

[6] Bucur, C., Tudorica, B., Oprea, S., Nancu, D., & Dusmanescu, D. (2021). Insights into Energy Indicators Analytics Towards European Green Energy Transition Using Statistics and Self-Organizing Maps. IEEE Access, 9, 64427-64444.

[7] Charalambides, A. G., Maxoulis, C. N., Kyriacou, O., Blakeley, E., & Frances, L. S. (2019). The impact of Energy Performance Certificates on building deep energy renovation targets. International Journal of Sustainable Energy, 38(1), 1–12.

[8] ERESEE 2020. (2020). 2020 Update of the long-term strategy for energy rehabilitation in the building sector in Spain, https://ec.europa.eu/energy/sites/ener/files/documents/es_ltrs_2020.pdf, accessed on 20th Feb 2022.

[9] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (2019). Ars Iuris Salmanticensis, 6(2), 253-254.

[10] UE. (2010). Directiva 2010/31/UE Eficiencia Energetica de los Edificios. UE.

[11] European Parliament and Council of the European Union. Directive 2012/27/EU, Official Journal of the European Union § (2012).

[12] Eurpstat Statistics Explained UE. (2022). Energy statistics - an overview, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_statistics_-_an_overview&oldid=552859, accesed on 21th Feb 2022.

[13] Building and Construction Agency. (2022) EPC official website by Ministry for Transport and Infrastructures of Malta. https://epc.gov.mt/faqs?l=1, accessed on 21th Feb 2022.

[14] Gatt, D., Yousif, C., & Street, B. (2018). Malta policy action plan report. University of Malta.

[15] Building and Construction Agency. (2022). Regulation Energy Performance L.N. 47 of 2018. https://bca.org.mt/regulation-energy-performance#:~:text=L.N.,47%20of%202018&text=These%20regulations%20promote%20the%20improvement,climate%20requirements%20and%20cost%2Deffectiveness, accessed on 22th Feb 2022.

[16] Gatt, D., Yousif, C., Barbara, C., Caruana, T., Degiorgio, M., & SBE19 Malta International Conference. (2019). EPBD Cost-optimal Analysis for Non-residential Buildings in Malta.

[17] Chudley, R., & Greeno, R. (2020). Energy Performance Certificate. In Building Construction Handbook (pp. 44–47). Routledge.

[18] Von Platten, J., Holmberg, C., Mangold, M., Johansson, T., & Mjörnell, K. (2019). The renewing of Energy Performance Certificates—Reaching comparability between decade-apart energy records. Applied Energy, 255.

[19] Yousif, C., Diez, R. M., & Martínez, F. J. R. (2013). Asset and operational energy performance rating of a modern apartment in Malta. Smart Innovation, Systems and Technologies, 22, 531–543.

[20] M.R. Mallia & O. Prizeman (2018) Energy Performance Certification, Is the software currently used in Malta Suitable for the energy assessment of its historic buildings?

[21] Malta (2019) Malta s 2030 National Energy and Climate Plan.

[22] I.E.A. (2014) International Energy Agency, Cumulative global energy efficiency investment by end-use sector in the New Policies Scenario, 2014-2035.

[23] Darivianakis, G., Georghiou, A., Smith, R. S., & Lygeros, J. (2019). The Power of Diversity: Data-Driven Robust Predictive Control for Energy-Efficient Buildings and Districts. IEEE Transactions on Control Systems Technology, 27(1), 132–145.

[24] Ding, Y., Ding, Y., & Nord, N. (2021). Data-driven analysis of electricity use for office buildings: A Norwegian case study. E3S Web of Conferences, 246, 4005.

[25] Kang, H., Lee, M., Hong, T., & Choi, J. K. (2018). Determining the optimal occupancy density for reducing the energy consumption of public office buildings: A statistical approach. Building and Environment, 127, 173–186.

[26] EUROSAI (2018). Energy Efficiency of Public Sector Buildings.

[27] Singh, M.K., Mahapatra, S. and Teller, J. (2013). An analysis on energy efficiency initiatives in the building stock of Liege, Belgium. Energy Policy, 62, 729-741.

[28] EPBD (2018). Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency.

[29] Ma, Y., & Reynders, G. (2019). Data-driven statistical analysis of energy performance and energy saving potential in the Flemish public building sector. Journal of Physics. Conference Series, 1343(1), 12051.

[30] Fabbri, K. (2013). Planning a regional energy system in association with the creation of energy performance certificates (EPCs), statistical analysis and energy efficiency measures: An Italian case study. Buildings, 3(3), 545–569.

[31] Anđelković A, S., Kljajić M, Macura D, et al. Building energy performance Certificate—A relevant indicator of actual energy consumption and savings? Energies. 2021;14(12):3455.

[32] Streicher, K. N., Padey, P., Parra, D., Bürer, M. C., & Patel, M. K. (2018). Assessment of the current thermal performance level of the Swiss residential building stock: Statistical analysis of energy performance certificates. Energy and Buildings, 178, 360–378.

[33] Schuepbach, E., Muntwyler, U., Schott, T., Jost, M., Renken, C., & Lanz, M. (2015). Swiss energy strategy 2050: Research on photovoltaic electricity production. In 2015 10th International Conference on Ecological Vehicles and Renewable Energies, EVER 2015. Institute of Electrical and Electronics Engineers Inc.

[34] Ji, C., Hong, T., Kim, H., & Yeom, S. (2022). Effect of building energy efficiency certificate on reducing energy consumption of non-residential buildings in South Korea. Energy and Buildings, 255, 111701.

[35] Ministry of Land, Infrastructure and Transport (MOLIT). (2014). The 1st Master Plan for Green building policy, MOLIT, South Korea.

[36] Ministry of Land, Infrastructure and Transport (MOLIT) (2019). The 2nd Master Plan for Green building policy, MOLIT, South Korea.

[37] Green Zone Surveys. (2022). Energy Performance Certificates, https://www.greenzonesurveys.com/services/commercial-epcs/, accessed on 4th Mar 2022.

[38] Bamdad, K., Cholette, M., Guan, L., & Bell, J. (2018). Building energy optimisation under uncertainty using ACOMV algorithm. Energy and Buildings, 167, 322-333.

[39] Attia, S., Hamdy, M., O'Brien, W., & Carlucci, S. (2013). Assessing gaps and needs for integrating building performance optimization tools in net zero energy buildings design. Energy and Buildings, 60, 110–124.

[40] Herrando, M., Cambra, D., Navarro, M., de la Cruz, L., Millán, G., & Zabalza, I. (2016). Energy Performance Certification of Faculty Buildings in Spain: The gap between estimated and real energy consumption. Energy Conversion and Management, 125, 141–153.

[41] Menezes, A. C., Cripps, A., Bouchlaghem, D., & Buswell, R. (2012). Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. Applied Energy, 97, 355–364.

[42] Abela, A., McGrath, P., Hoxley, M., & Goodhew, S. (2013). A comparative analysis of implementation of the Energy Performance of Buildings Directive in the Mediterranean. International Journal of Law in the Built Environment, 5(3), 222–240.

[43] Abela, A., Hoxley, M., McGrath, P., & Goodhew, S. (2013). An investigation into the practical application of residential energy certificates. Smart Innovation, Systems and Technologies, 22, 491–499.

[44] D. Gatt and C. Yousif. (2017). "Interreg Europe ZEROCO2 technology options towards NZEB (NZCO2EB) for Malta". Malta.

[45] D.Azzopardi, K. Spiteri and P. Cassar. (2018). Cost Optimal Levels for New Offices in Accordance with the Energy Performance of Buildings Directive (Recast) 2010/31/EU. Malta: CASAingenieria.

[46] European commission. (2012). Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council. Official Journal of the European Union, (C115), 1–28.

[47] European Parliament, Commission (2012) European Parliament, Commission delegated regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating.

[48] J. Gangoso (2020). Statistical Analysis of Energy Performance Certificates of Maltese Dwellings. University of Malta. Malta.

[49] Building Regulation Office (2011). Study to Establish Cost-Optimal Energy Performance Levels in New and Existing Residential Buildings in Malta in Accordance with Directive 2010/31/EU on the energy performance of buildings.

[50] Building Regulation Office (2015). "Nearly-zero energy buildings plan for Malta. Malta.

[51] N. Heijmans and X. Loncour. (2015). N. Heijmans and X. Loncour, "Changes in EPCs scales and layouts," no. 692447, pp. 1–4.

[52] López-González, L. M., López-Ochoa, L. M., Las-Heras-Casas, J., and García-Lozano, C. (2016). Energy performance certificates as tools for energy planning in the residential sector. The case of La Rioja (Spain). Journal of Cleaner Production.

[53] Ministerio de Fomento. (2019). "Documento Básico HE Ahorro de Energía 2019," *Código Técnico la Edif.*, pp. 1–129.

[54] X. Loncour and N. Heijmans. (2018). "Certification , Control system and Quality - 2018 Status in February 2018," no. February.

[55] Di Corso, E., Cerquitelli, T., Piscitelli, M. S., & Capozzoli, A. (2018). Exploring energy certificates of buildings through unsupervised data mining techniques. In Proceedings - 2017 IEEE International Conference on Internet of Things, IEEE Green Computing and Communications, IEEE Cyber, Physical and Social Computing, IEEE Smart Data, iThings-GreenCom-CPSCom-SmartData 2017 (Vol. 2018-January, pp. 991–998). Institute of Electrical and Electronics Engineers Inc.

[56] Tommerup, H., & Svendsen, S. (2006). Energy savings in Danish residential building stock. Energy and Buildings, 38(6), 618–626. de Energía 2019," Código Técnico la Edif., pp. 1–129, 2019.

[57] Climate Data. (2022). Climate in Malta: climogram, temperature and climate tables, https://es.climate-data.org/europe/malta/malta-1443/, accessed on 15th Mar 2022.

[58] L. Agon (2020). "Statistical Analysis of Energy Performance Certificates of Maltese Schools". Malta.

[59] John, J.A y P. Prescott. (1975). "Critical Values of a lest to Detect Outliers in Factorial Experiments", en Applied Statistics, vol. 24, pp. 56-59.

[60] Mongomery, D. C. (2017). Montgomery: Design and Analysis of Experiments.

[61] Statgraphics 19 centurion. (2022). Statgraphics software official website, https://www.statgraphics.com/, accessed on 26th Apr 2022.