ANALYSING THE "PERFORMANCE GAP" BETWEEN ENERGY PERFORMANCE CERTIFICATES AND ACTUAL ENERGY CONSUMPTION OF NON-RESIDENTIAL BUILDINGS IN MALTA

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DECLARATION

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

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ABSTRACT

The updated EU energy performance of buildings directive 2018/844 stipulates that measures need to be taken to accelerate building renovation to achieve carbon neutrality by 2050. A key tool is the energy performance certificates (EPCs), which so far have proved to be virtually ineffective in driving change, due to the low level of trust in their credibility. This is mainly manifested by the existence of a significant energy “performance gap” between the EPC and the building’s actual energy use intensity. This thesis has investigated this “performance gap” between the non-residential national software SBEM-mt and the actual energy use intensity for three non-residential clusters having different building services’ engineering complexities, and found it to be both significant and unpredictable for all of them.

An alternative approach based on operational rating has been proposed, which considers the actual energy consumption of a building, in order to determine its energy use intensity (EUI). Inspired by the UK benchmarks for non-residential buildings, a dynamic, transparent, reliable and repeatable tool has been developed, whereby good practice benchmarks for 29 non-residential categories have been calculated for Malta, based on the concept that energy use in buildings may be split into weather-independent and weather-dependent components. The tool considers a systematic bottom-up approach taking into consideration Malta’s total degree days, ventilation requirements, heating load as well as sensible and latent cooling loads, besides others. Results showed that the total EUI for the different categories is very similar to that of the UK. Malta’s total degree days are lower, yet, the latent load for cooling more than counterbalances the lower heating demand. Comparison between the results of this tool and the actual EUIs for the three cluster buildings was found to be convergent and consistent. The tool can be used to provide Malta with verified benchmarks upon which policies and energy investment decision making can be based to achieve an improved efficient energy rating towards the road to carbon neutrality.

Keywords: Energy performance gap, operational rating, benchmarks, energy performance certificates, SBEM 4.2c

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ABBREVIATIONS

ACC	Air Cooled Chiller
ADEME	French Environment and Energy Management Agency
AHUs	Air Handling Units
AM	Applications Manual
AR	Asset Rating
ASHRAE	American Society of Heating, Refrigeration and Air-conditioning Engineers
BEECS	Building Energy Efficiency Certification System
BER	Building Emission Rating
BP	British Petroleum
BPIE	Building Performance Institute Europe
BRE	Building Research Establishment
BRO	Building Regulations Office
BSO	Building Stock Observatory
CB	Chilled Beam
CDD	Cooling Degree Days
CEN	European Standardization Organizations
CFCs	chlorofluorocarbons
CIBSE	Chartered Institution of building Services Engineers
CIS	Commonwealth of Independent States
CO_2	carbon dioxide
COP	Coefficient of Performance
CSSD	Central Sterilisation Department
DD	Degree Days
DECs	Display Energy Certificates
DHW	Domestic Hot water
DOE	Department of Energy
ECG	Energy Consumption Guides
EEA	European Environment Agency
EER	Energy Efficiency Ratio
EnMS	Energy Management System
EPBD	Energy Performance of Buildings Directive
EPCs	Energy Performance Certificates
EPRDM	Energy Performance Rating of Dwellings Malta
ESD	Effort Sharing Decision
EU	European Union
EUI	Energy Use Intensity
FCU	Fan Coil Unit
GHGs	Green House Gasses
GP	Good Practise
HDD	Heating Degree Days

HVAC	Heating, Ventilation and Air-conditioning
IAQ	Indoor Air Quality
IEA	International Energy agency
IEQ	Indoor Environmental Quality
ISE	Institute for Sustainable Energy
ITU	Intensive Therapy Unit
ISO	International Standard Organisation
KPIs	Key Performance Indicators
kWh	kilo-Watt-hour
LN	Legal Notice
MDH	Mater Dei Hospital
MS	Member States
MS	Member States
Mtoe	Million Tonnes of Oil Equivalent
MVA	Mega Volt Ampere
NCT	Nero Cover Design
NECP	National Energy and Climate Plan
NP	Normal Practice
NZEB	Near-Zero Energy Buildings
OECD	Organisation for Economic Co-operation and Development
OR	Operational Rating
PEF	Primary Energy Factor
PEFs	Primary Energy Factors
PMV	Predicted Mean Vote
PPD	Percentage of People Dissatisfied
ppm	Parts per Million
RES	renewable energy sources
RH	Relative Humidity
RMS	Root Mean square
SBEM-mt	Simplified Building Energy Modelling Malta
SCOP	Seasonal Coefficient of Performance
SEER	Seasonal Energy Efficiency Ratio
SER	Standard Emission Rating
SFP	Specific Fan Power
T	Temperature
TDD	Total Degree Days
TM	Technical Manual
TMY	Typical Mereological Year
UCL	University College London
UK	United Kingdom
USA	United States of America
VRF	Variable Refrigerant Flow

1 INTRODUCTION

1.1 Background and project concept

The management of energy consumption in the building sector is crucial in achieving the EU's energy and environmental goals. In fact, past experience [1] has shown that energy-efficient buildings can have a sustained positive effect on curbing energy demand while improving the quality of citizens' life and delivering additional benefits to the economy and to society [2].

Since 2002, the European Union has been the forerunner in devising legislation and other methods of addressing energy consumption in buildings, considering that this sector occupies a substantial share of energy consumption reaching up to 41.7%, i.e. 27.2% residential and 14.5% non-residential [3]. The EU enacted the Energy Performance of Buildings Directive (EPBD) in 2002, with a recast directive 2010/31/EU [4] in 2010, and a further update 2018/844/EU in 2018 [5]. Together, these directives promote policies which aim to:

- achieve a highly energy-efficient and decarbonised building stock by 2050;
- create a stable environment for investment decisions; and,
- enable consumers and businesses to make better informed choices that save energy and money.

Moreover, non-residential buildings in Europe are estimated to occupy 7 billion m^2 of useful floor area. The EU requires new buildings and renovations to be nearly zero-energy as of January 2021 [4]. Energy consumption is energy use plus energy wasted. Hence, the energy efficiency of buildings by reducing waste can be considered as an independent source of energy. Apart from this energy source gained from reducing waste being the cleanest and most secure, it is also the cheapest energy efficient strategy not being used at all. This type of energy is one of the most cost-effective ways of supporting the transition to a low carbon economy, which in addition prompts further investment opportunities while creating growth and employment. Energy efficiency thus reduces waste and brings actual energy consumption closer to efficient energy use and more in line with the principal themes in ISO 50001 Energy Management Systems (EnMS) [6] – which is a global target.

The EU requires Member States to carry out studies which establish benchmarks for different categories of such buildings within or near the zero energy status [7]. In directive 2018/844 the EU placed more importance on the renovation of existing buildings, requiring all Member States (MS) to devise a national building renovation plan, incorporate smart energy measures in building renovation, introduce electric charging points in new and renovated buildings according to set criteria, and that buildings should have energy renovation passports, besides other measures. The emphasis is that buildings should aim to achieve valid energy savings and approach real carbon neutrality by 2050.

Based on the latest EU statistics issued in 2019, the annual energy consumption for non-residential buildings in all Member States for 2017 was 154Mtoe (1 Mtoe = 11,630 million kWh) [3] as shown in Table 2-1. The largest consumers are Germany (34.45 Mtoe) followed by France (28.83 Mtoe) and Italy (18.24 Mtoe). Malta's share in this is 0.5Mtoe (5,815MkWh) of which 0.13 Mtoe (1,512 MkWh) are allocated to non-residential buildings as shown in Table 1-1 and Figure 1-1. Though this may seem to be a relatively low value, non-residential buildings in Malta have the highest weight to carry in comparison to total energy consumption. In fact, the percentage share of energy consumed by non-residential buildings in Malta stands at 26.0% of the total energy consumption, making Malta the topmost particular consumer in the EU followed by France (16.98%), Germany and Estonia (16.86%) [3].

Hence, being a predominantly cooling load country, using mainly electrically-run plants, any reduction of energy consumption associated with non-residential buildings will have a considerable effect on the actual primary energy demand in this country. This becomes more significant on considering the multiplier effects by two or more of the above values associated with the primary energy factors (PEFs) conversions that are involved in the transformation of fuel to electricity.

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Table 1-1: Malta primary energy use by sector 2017 [3]

Sector	Industry	Transport	Residential	Services	Agriculture & Fisheries	Others	Total
Mtoe	0.06	0.21	0.09	0.13	0.01	0.00	**0.5**
million kWh	697.80	2442.30	1046.70	1511.90	116.30	0.00	**5815.0**
Percentage	12.0%	42.0%	18.0%	26.0%	2.0%	0.0%	

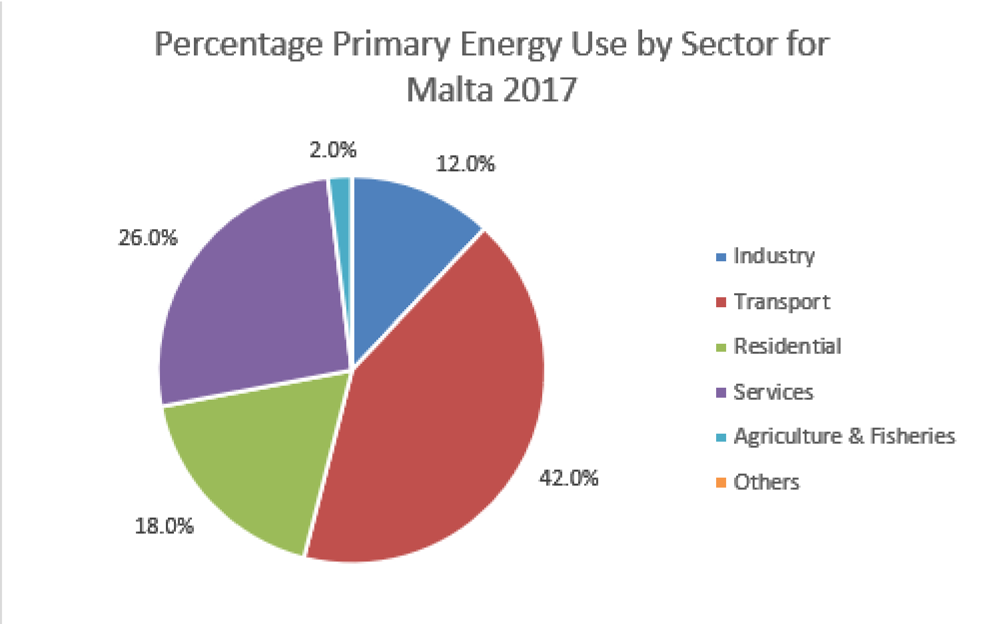


Figure 1-1: Percentage of primary energy use by sector for 2017 [3]

On the other hand, Malta's energy sources are almost totally imported, with a small percentage being generated from locally available renewable energy sources [8]. This leaves the Island heavily dependent, insecure and vulnerable to price fluctuations, political and environmental concerns and conditions.

One effective way of reducing this dependency is to manage and control energy consumption in buildings. Often, the existing energy wastage in building stems from three primary sources, namely, excessive energy flow through the building envelope, uncontrolled use of heating, ventilation and air-conditioning and lack of awareness with regards to energy efficiency and conservation measures.

As such the obligation towards gaining Energy Performance Certificates (EPCs) is a step in the right direction from a sustainability point of view, as well as to conserve the finite fossil fuel resources and mitigate global warming effects. In attaining EPCs, the economic sector is also preserved and allowed to manifest itself through sustaining jobs in our industries and thriving through reaching modern European ways of working and thus also encourage consumers to seek out more efficient buildings, when renting or buying.

Malta has two national energy performance rating methodologies. One designated to dwellings, known as the Energy Performance Rating of Dwellings Malta using the EPRDM [9]; and one addressing non-dwellings, using software known as the Simplified Building Energy Modelling Malta (SBEM-mt) [9].

So far, benchmarks for near-zero energy buildings have been proposed for dwellings and offices [10], however these do not apply to existing or new non-residential buildings. The use of the SBEM-mt software to create such benchmarks for non-residential buildings is not possible because in most cases, benchmarks are usually based on results of statistical analysis of large databases of different building categories certificates [11]. Until 2018 in Malta, there were only around 3,000 EPCs for non-residential buildings in Malta. Most of these certificates were allocated to public authority buildings such as public schools, clinics, hospitals and government departments [12]. According to the Energy Performance of Buildings Directive (EPBD), privately-owned non-residential buildings are not required to have an EPC unless they are up for sale, rent or being newly constructed. Therefore, it is quite challenging to create benchmarks based on such a small sample of buildings or on buildings that belong to public authorities, many of which are classified as historical buildings or date back to the 1950s. Thus, making this sample non-representative of the majority of the non-residential buildings of Malta.

Moreover, if one were to compare the EPC Primary (or Source) Energy Use Intensity (EUI) to the Actual (or Site) EUI, and find that there is a significant gap between them, then it cannot be justified to use generated EPCs as benchmarks, because this would make it either too easy to achieve or impossible to attain, depending on the size of the gap.

While the EU is demanding that benchmarks need to be defined for all building categories as soon as possible to kick start the building renovation plan 2021-2030 [5], the case for Malta shows that statistical analysis of EPCs of non-residential buildings cannot provide any meaningful benchmarks for all the different categories. The concept of this thesis is therefore to propose an alternative route that will reliably produce realistic benchmarks, which will support national building energy renovation plans for non-residential buildings. However, in order to fully justify this approach, it is important to confirm first and foremost whether a “gap” exists between the EPCs of typical well-designed buildings and their respective actual energy consumption or not. If a gap were to be found, one would need to consider an alternative strategy to determine ambitious yet achievable benchmarks for different categories of buildings to form the basis for any plans to kickstart or encourage energy renovation schemes for the years 2021 to 2030.

1.2 Research question, aims and objective

The key research question of this PhD thesis is:

Is there a gap between energy performance certificates and actual energy consumption and if so, how can Malta produce reliable and representative energy performance benchmarks for non-residential buildings?

The aim is to develop methodologies for the design of suitable representative benchmarks of EUIs for Malta’s different types of non-residential buildings, upon which energy renovation plans can be built.

The objectives may be summarised as follows:

a) Determine the extent of any existing gap between the energy use intensities (EUIs) of the Energy Performance Certificates (EPCs) and the actual annual energy use intensities measured on-site.
b) Establish an objective approach that will provide a definitive answer to whether the site EUI as given in the EPCs can be used to represent the actual EUI of various types of non-residential buildings in Malta.

c) Devise a reliable methodology that provides site EUI benchmarks for different non-residential buildings, which can be used as “good practice” guidance for new or renovated buildings or as base Energy Performance Indicators (EPIs) in audits or use energy management system (EnMS) for various types of non-residential buildings.

1.3 Relevance

Malta’s National Energy and Climate Plan (NECP), published in 2019, follows the scope of the Energy Union that covers its five dimensions namely, decarbonisation, energy efficiency, energy security, internal energy market, and research, innovation and competitiveness [13].This aims to ensure the achievement of the Union’s 2030 long-term objectives and targets, in line with the Union’s international commitments under the Paris Agreement. As per 2017 EU data reporting for 2015, in Malta the energy consumption in non-residential buildings stands at over 1,512 million kWh (0.13Mtoe) per year [14], which is relatively substantial. Credible energy efficiency measures need to be implemented in order to reach these objectives.

While the 2019 NECP summary outlines the progress of energy efficiency in buildings, it also highlights the fact that during the public consultation process, the NECP also only mildly considered energy efficiency in buildings as a contributory factor in drawing its conclusions. The plan itself falls short of proposing radical changes for buildings acting as a first line of defence against energy wastage. The main reason drawn in these conclusions is the low economic benefit potentially garnered from applying energy efficient measures.

Page 46 of the NECP [14] states:

“*A similar situation exists in government owned and occupied buildings. A case study commissioned by the Government of Malta to evaluate possible options to renovate a number of typical government office blocks highlighted that given the low energy intensiveness of activities in the selected buildings, the return on investment for the majority of the renovation options is quite low”.*

However, in the same document the NECP declares that it is aware of Malta's commitments to develop a long-term building renovation strategy that should have been submitted to the European Commission on 10 March 2020, but to date remained unpublished.

Clearly, there is an issue of data availability and lack of studies on energy performance of buildings, in particular on non-residential buildings. In fact, the same document declares that *"the total floor area to be renovated or the equivalent annual energy savings to be achieved from 2021 to 2030 under Article 5 on the exemplary role of public bodies' buildings of Directive 2012/27/EU is not available"*.

On the other hand, when one considers the 2015 Nearly Zero Energy Buildings Plan for Malta [15], it is evident that there is very little information on what non-residential buildings are expected to attain in terms of energy efficiency. The relevant primary energy demand limits are given for office buildings only. The mean primary energy rating for offices, built according to the minimum energy performance requirements Technical Document F [16], was found to be 357 kWh/m².year while the cost optimal level based on the use of the SBEM-mt software, was found to be 290 kWh/m².year. These EUIs do not include for the equipment load.

One also notes that the primary energy to electricity conversion factor used in SBEM-mt is taken as 3.45 (equivalent to 0.878kg CO_2 per kWh site energy consumption), when the EU is already considering a value of 2, while Malta's actual energy conversion factor after introducing the interconnector a.c. cable to Sicily, Italy and converting all the power stations to operate with natural gas, stands at around 1.5 (equivalent to 0.383kg CO_2 per kWh of site energy consumption in 2018) [17].

Similarly, when one looks at the 2018 cost-optimal studies that were published for seven non-residential buildings, namely homes for the elderly, hotels, restaurants, shops, schools sports complexes and new (excluding renovated) offices [18], the figures are once more based on simulations of the SBEM-mt software.

Clearly, the efforts that have been carried out to date fulfil some of the most important obligations that Malta has towards the EU EPBD and have set the foundation for a more energy efficient building scenario from the legislative point of view.

However, the above measures are not guaranteed to make new or existing non-residential buildings achieve energy performance excellence in real terms, to support Malta's endeavours to reduce carbon dioxide emissions in line with the EU Policy towards a carbon neutral continent by 2050. There is a need for assurance and evidence-based studies to confirm that the energy performance levels are indeed Best Practice models for the different categories of buildings. Moreover, the existing studies so far have only covered a limited number of non-residential building categories, leaving many others without any benchmarks or requirements for better energy efficiency.

Therefore, this thesis looks to answer a number of frequently asked questions that are often overlooked by policy makers when enacting policies or when designing fiscal support schemes.

Another important contribution of this study is to provide best practice benchmarks for all of the non-residential buildings, divided into 29 different categories, thus supporting the drive towards a collective approach of excellence in energy saving. Best practice implies the ambitious yet achievable energy efficiency levels that buildings should attain to be classified as energy efficient.

Finally, this research develops an MS Excel worksheet tool that can be updated along the years as more operational data of building categories is made available in Malta. In so doing, the best practice benchmarks will start to approach the nearly zero-energy status that the EU is hoping to achieve throughout the European Union. This tool is arranged in such a way that it can be converted into a simple software routine to assist architects and engineers to design buildings to optimum levels.

1.4 Organisation of this Thesis

This brief introduction links to the literature review in Chapter two, which is focussed on the importance of reducing energy use, particularly in buildings. It discusses the EPC asset rating certification in Europe and compares it with other types of systems, such as the Operational Rating of UK Display Energy Certificates (DECs) and different methodologies used in the US and Asia.

Chapter three defines an appropriate methodology for the research. First it illustrates the steps for a quantitative approach in order to see if a performance gap really exists by comparing the predicted energy used, to that measure on site, for three cluster types of non-residential buildings. Once a substantial gap is found, this chapter moves towards a qualitative methodology to find alternative solutions so Malta can have suitable benchmarks for a number of non-residential buildings as good practice yardsticks to measure the energy use intensities in new or renovated scenarios.

Chapter four presents three case studies of energy consumption for three types of non-residential buildings, namely schools, offices and healthcare buildings. Together these three building types account for over 47% by area [19] of non-residential buildings in Malta. This chapter also outlines the local National Calculation Method (NCM) based on the UK Building Research Establishment (BRE) Simplified Building Energy Model which was developed and adapted for the local Maltese climate (SBEM-mt v4.2c).

Chapter five proposes a new approach based on the Degree Day Methodology for energy estimation to create energy performance benchmarks for 29 categories of non-residential buildings. This chapter goes further to identify the airflow required for such types of buildings in the 29 categories and uses non-adapted low polluting buildings based on the predicted mean vote – i.e. the percentage of people dissatisfied technique. Also, this chapter analyses the local meteorological data for three consecutive years and uses them to devise a template that calculates the energy used related to the change in moisture content between inside and outside conditions for each hour of operation, for each categorised benchmarked building. This, together with the energy use in the degree-day calculations for which the cooling degree-hours are considered for the time the equipment is in operation, and the energy use is weather-independent, provides the final harmonised good-practice benchmark for the 29 non-residential building categories, harmonised to Malta’s weather climate.

Chapter six compares the generated “good practice” site EUI benchmarks to the actual on-site energy consumption measurements taken for the three clustered buildings that were studied initially in Chapter four.

Finally, chapter seven concludes the thesis with a critical review of the research, including its contribution to knowledge, research impact and limitations together with suggestions for further investigation and increased progress in efficient energy use.

2 LITERATURE REVIEW

2.1 Introduction

2.1.1 The primary energy issue

Energy is indispensable for all. Ever since the industrial revolution, fossil fuels seemed to be the ideal energy source, and vast quantities of these fuels have been used to power the world's economies and deliver unprecedented prosperity to vast numbers of countries and people.

The demand for primary energy has been steadily increasing in step with economic growth, and the use of fossil fuels acted as a prerequisite for the birth of a new industrial movement that transformed the world.

As shown in Figure 2-1 the BP 2019 edition of Energy Outlook [20] showed that the world primary energy consumption significantly increased from 6.8 billion tonnes of oil equivalent (toe) in 1990, to 13.5 billion tonnes of oil equivalent in 2010. This is expected to continue to grow in the coming years due to an increase in the world population, emerging economies such as China and India, as well as an increase in production.

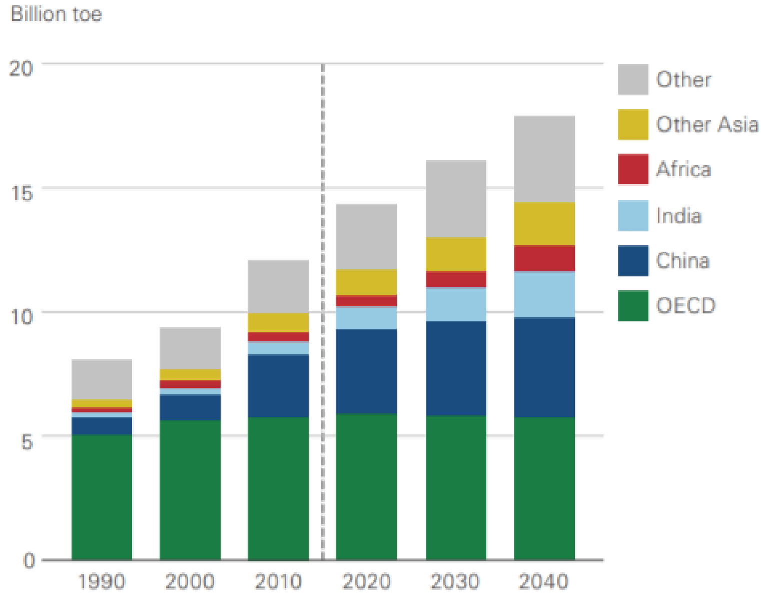


Figure 2-1: Primary Energy Consumption by Region [20]

The contribution of nuclear and renewable energies in 2017 was limited to around 15% of total energy consumption. Although, the rate of increase of renewable energy seems to surpass other fuels for all of the four energy development scenarios up to 2040, as shown in Figure 2.2.

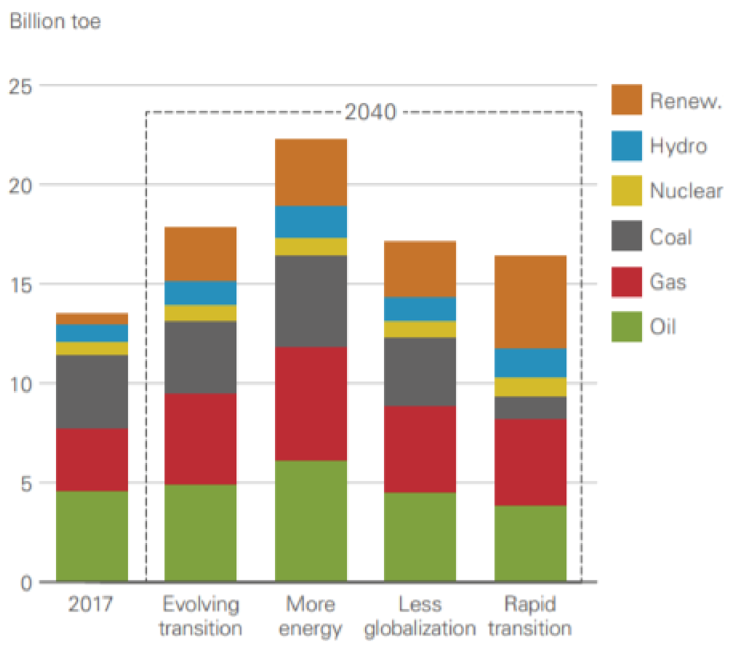


Figure 2-2: Primary energy consumption by fuel type [20]

Many centuries ago, firewood and charcoal were used for cooking or heating because they were readily available. Later, as steam locomotives used coal as their primary fuel source, coal mines were developed. This continued until the mid-19th century during the modest beginnings of the oil industry before petroleum rose to its now global prominence. Initially, kerosene was predominant as the principal product used mainly for lighting and heating of buildings. However, with the development of new drilling technologies for oil wells in the late-19th century, the petroleum industry found a new footing. This led to mass-primary energy consumption of the fuel, since it is highly versatile in powering transportation in the form of automobiles, ships, planes, and its applicability to generate electricity, heating and hot water supplies for buildings [21].

2.1.2 Use of fossil fuels

The Earth maintains a constant ambient temperature by balancing the energy absorbed from the sun against the infrared radiation emitted from the earth to space. However, as a result of this industrialisation, if heat-absorbing gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs) continue to increase, the temperature in the atmosphere will rise, because of the greenhouse effect.

This greenhouse effect, which puzzled climate experts for many years, was finally settled in a scientific paper that was published in the Nature journal [22] in April 2012. In this paper, Dr Robert M. DeCanto et al. showed how an increase in carbon dioxide levels in the atmosphere contributed to rising temperatures millions of years ago.

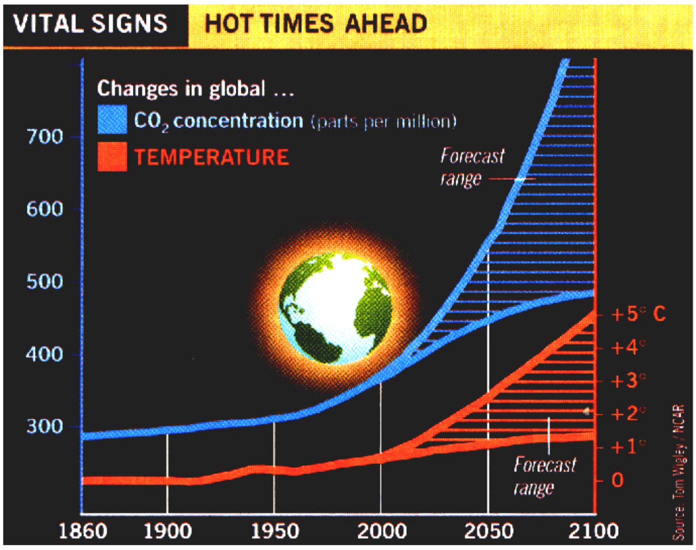


Figure 2-3: Changes in global temperatures and CO_2 concentrations during the years [23]

DeCanto et al.'s conclusions had wide-ranging implications for the climate science scenario. They had solved the question of whether increased carbon dioxide emissions led to a rise of temperature, or whether – as climate sceptics argue – a rise in temperature has led to an increase in carbon dioxide levels.

In short, by studying past extreme warming events since around 52 million years ago that were linked to massive carbon release from thawing permafrost, this study concluded that carbon dioxide emissions must be reduced if humanity is to survive and avoid extreme disasters. This led to various international treaties such as the Montreal, Kyoto, and Paris Agreements [24], which in turn on 11 December 2019 brought the European Green Deal [25] accord. This is now considered as an integral part of the European Commission's strategy to implement the United Nation's 2030 agenda and the sustainable development goals, namely to:

a) Stop the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change.
b) Increase the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production.
c) Make finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

2.1.3 Limitations of fossil fuels

Besides the global warming effect caused by excessive emissions, significant and harmful phenomena are being experienced by the world's communities, affecting their lives and health. Such phenomena include rising sea levels, increasing occurrences of wildfires, dangerous heat waves and storm events, and increasingly severe droughts even in places where such events were not so common up to a few years ago [26].

Another problem associated with fossil fuels consumption is the higher rate of consumption than that of new discoveries of fossil fuel sources, which makes the initial sources finite and calls for the need to preserve these sources for other more important uses than energy generation [26].

Additionally, these finite fossil fuel resources are unevenly distributed on the globe, which has led to significant conflicts and wars between nations. Notwithstanding the imperfect nature of the energy market, competition is high, and consequently, some governments tend to use these resources to control or exert advantage over other countries with politically motivated disruptions [27].

Europe stands at a significant disadvantage, because most of its energy demand is overly dependent on fossil fuel imports, given that the inland indigenous fossil fuel sources are very limited, as shown in Figure 2-4. As presented in the BP 65th edition of Primary Energy Presentation Slides [28] its production to reserves ratio in all regions is the lowest in the world.

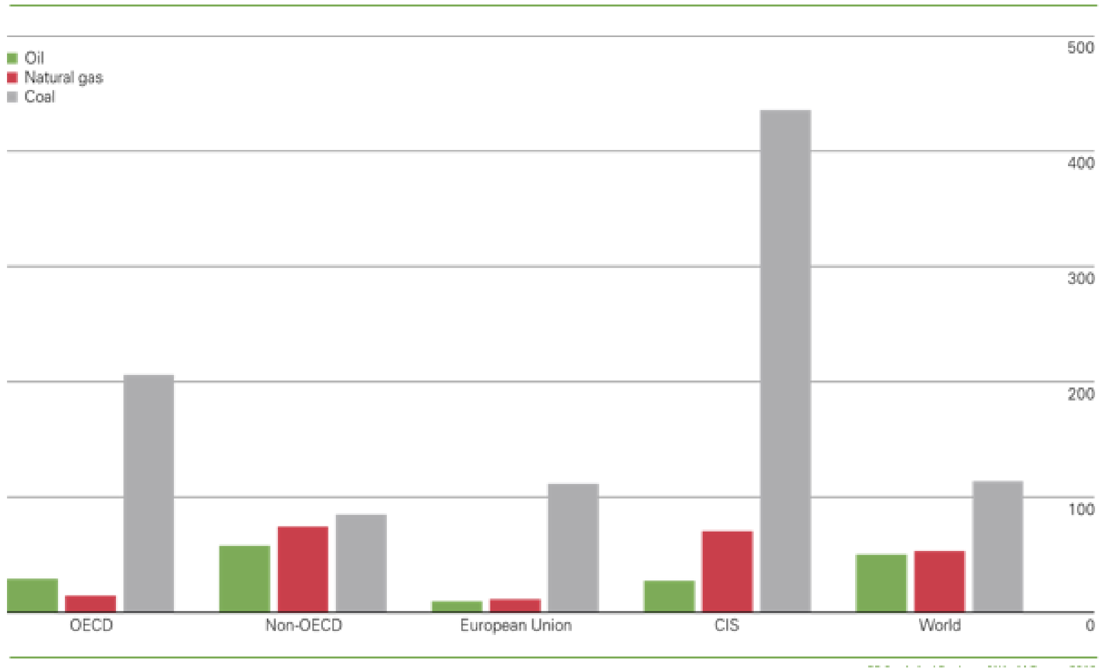


Figure 2-4: Fossil fuel reserves to production ratio at end 2015 [28]

2.1.4 EU energy policy

Notwithstanding the above shortages, the EU has actively committed itself to the Kyoto Protocol and the Paris Agreement by devising and implementing several directives to reach the committed targets. The targets set by EU leaders in 2007 and enacted in legislation in 2009 are now known as the Renewable Energy Directive 2009/28/EC and the European Green Deal [25]. These were translated into targets for the EU to achieve by 2020, as shown in Figure 2-5.

The three key binding targets are:

- 20% cut in greenhouse gas emissions (from 1990 levels);
- 20% of EU energy from renewables (from 1990 levels);
- 20% improvement in energy efficiency (from 2005 levels).

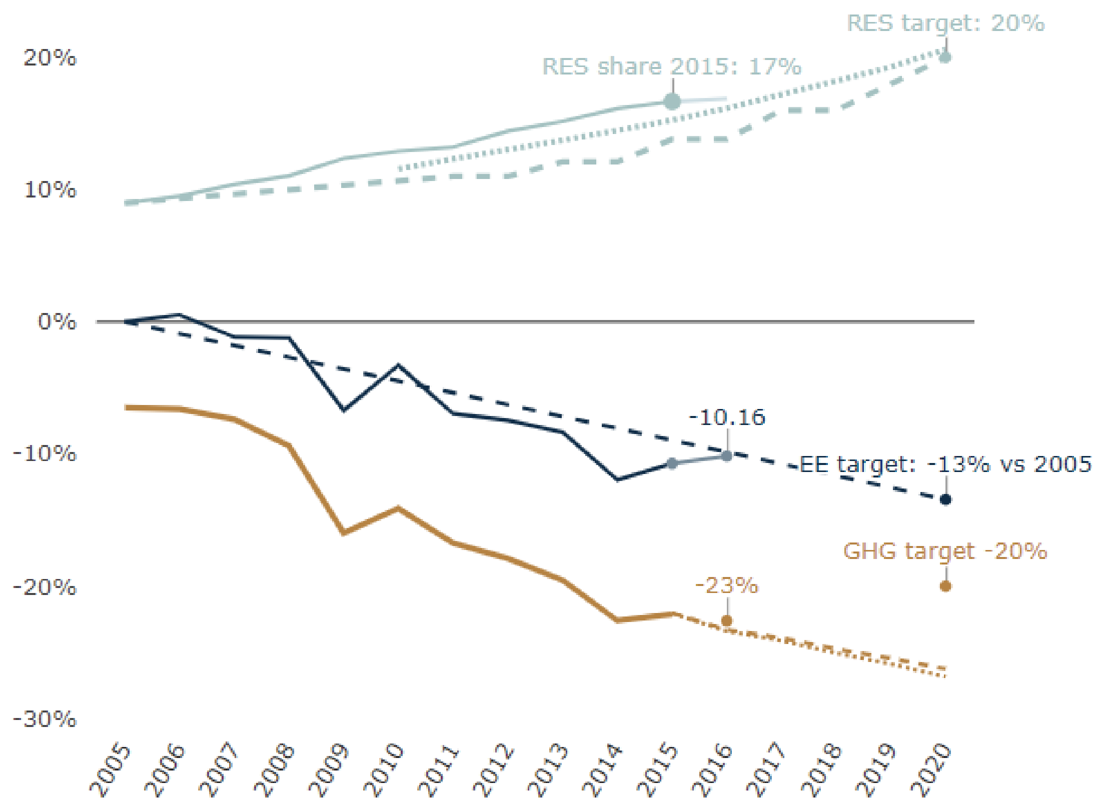


Figure 2-5: EU progress towards the 2020 climate and energy targets [29]

In fact, these legislations are already in place, which helped the EU to comfortably foresee achieving its 2020 target and push for stricter targets for 2030, as shown in Figure 2-6. The new targets for 2030 have been set by the updated directives (EU) 2018/2001 [30] to achieve 32.5% energy efficiency and (EU) 2018/2002 [31] to achieve at least 32% renewable energy share, while the carbon dioxide reduction target has been updated to 40%, under the 2030 EU Climate and Energy Framework [32].

A new long-term strategic vision for 2050, which the European Commission has set out in November 2018, provides a range of challenging but feasible pathways for the transition towards climate neutrality. These trends would all necessitate shifts in many areas of energy use across member states, not least towards the intensified generation of low to zero carbon-based energy [33], as well as considerable savings in energy consumption.

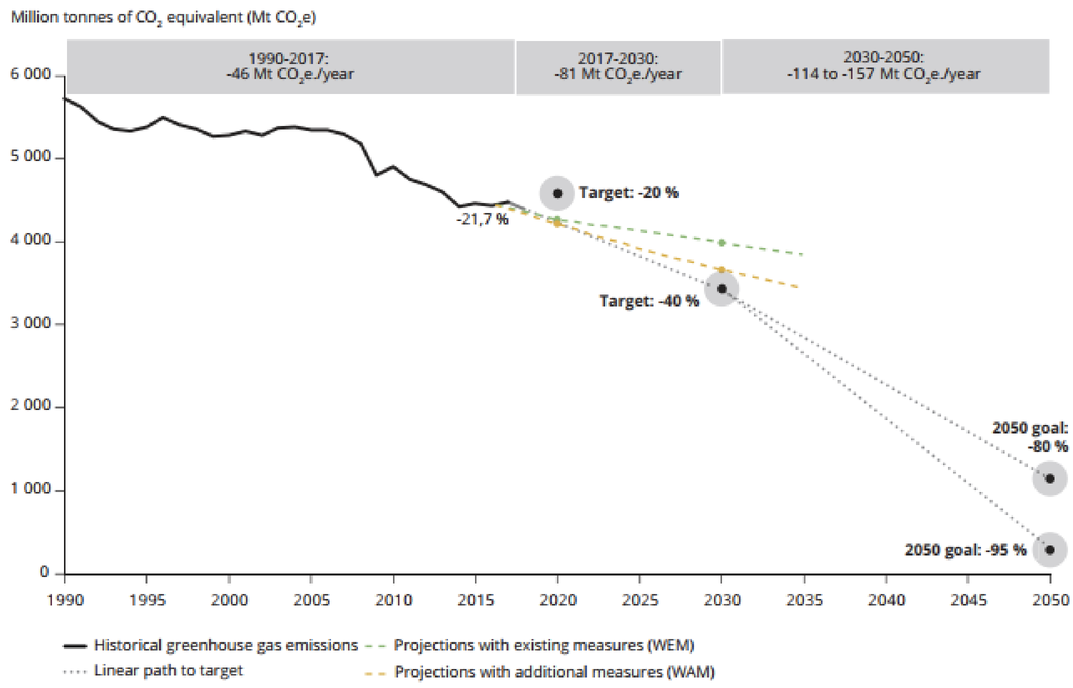


Figure 2-6: Greenhouse gas emission trends, projections and targets for the EU [33]

As such, the 2012 Energy Efficiency Directive 2012/27/EU[34] established a set of binding measures to help the EU reach its 20% energy efficiency target by 2020. Under this Directive, all EU countries were required to use energy more efficiently at all stages of the energy chain, from production to final consumption. This was augmented by an updated directive (EU) 2018/2001 [30] which will see the energy efficiency target progressing to 32.5% by 2030.

In fact, according to the Eurostat Yearbook 2019 [35], 28 years after the signing of the Kyoto Protocol agreement, the greenhouse gas emissions (using year basis 2016) in the EU-27 were down by 21.7% [36] when compared to 1990 levels. This represents an absolute reduction of 1,018 million tonnes of CO_2-equivalent, putting the EU on track to surpass its 2020 target, which is to reduce GHG emissions by 20% by 2020 compared to that of 1990.

As for the future, although the RES and GHG emissions reduction targets for 2020 are on track, meeting the energy efficiency target appears to be increasingly difficult to achieve.

On the other hand, as shown in Figure 2.7 taken from the BP statistical review, the energy used in buildings is the second largest in all energy usage categories all-over the world, and is steadily increasing.

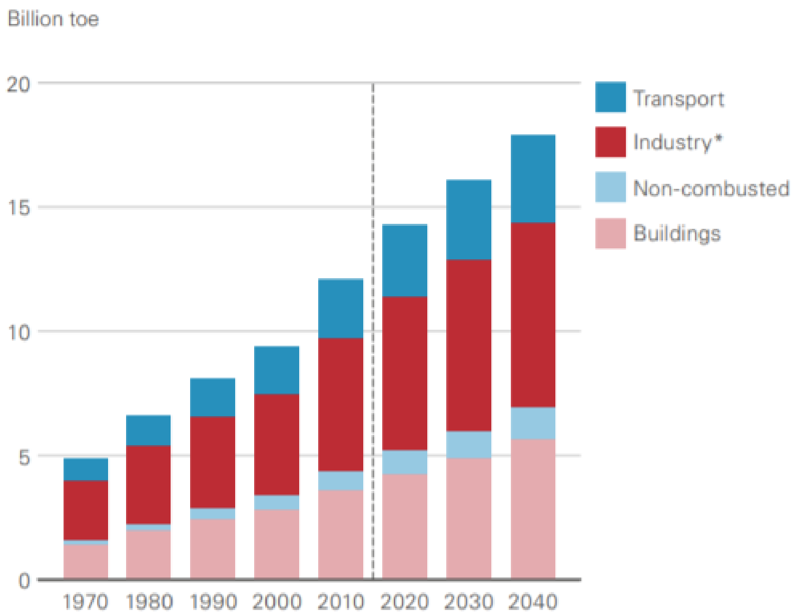


Figure 2-7: Primary energy consumption by sector [37]

In fact as shown in Table 2-1 this trend is even found in the EU which from latest published data [14] showed that the final energy consumption by sector for 2017 residential consumption stood at 288.0Mtoe (27.3%) and services (non-residential) stood at 154.0Mtoe (14.5%), which together make up the highest energy consumer even surpassing transport.

Table 2-1: Final energy consumption by sector
in the EU, year basis 2017 [3]

Mtoe 28 Member States	**Industry**	**Transport**	**Residential**	**Services**	**Agriculture & Fisheries**	**Others**	**Total**	**Non-residential EUIs share of total per MS**
EU-28	**261.0**	**326.9**	**288.0**	**154.0**	**25.8**	**4.3**	**1060.0**	14.5%
Share (%)	**24.6%**	**30.8 %**	**27.2%**	**14.5%**	**2.4%**	**0.4%**		
MT	**0.06**	**0.21**	**0.09**	**0.13**	**0.01**	**0.00**	**0.5**	**26.0%**
FR	26.54	45.36	40.65	23.83	4.14	0.48	**141.0**	16.9%
DE	56.27	57.24	56.55	34.45	0.00	0.09	**204.6**	16.8%
EE	0.46	0.80	0.94	0.47	0.13	0.00	**2.8**	16.8%
IT	24.93	34.53	32.90	18.24	2.92	0.10	**113.6**	16.1%
LV	0.79	1.08	1.20	0.61	0.20	0.00	**3.9**	15.7%
NL	13.84	10.67	9.70	6.83	3.83	0.08	**45.0**	15.2%
CY	0.23	0.68	0.34	0.23	0.05	0.02	**1.6**	14.8%
DK	2.34	4.22	4.55	2.01	0.72	0.02	**13.9**	14.5%
SK	3.45	2.77	2.11	1.43	0.14	0.00	**9.9**	14.4%
UK	22.75	41.85	37.08	17.11	1.36	1.07	**121.2**	14.1%
BE	10.49	8.86	8.11	4.60	0.79	0.04	**32.9**	14.0%
EL	3.10	5.82	4.41	2.19	0.30	0.23	**16.1**	13.6%
ES	18.97	31.72	15.44	10.41	2.65	0.20	**79.4**	13.1%
CZ	6.70	6.62	7.19	3.19	0.64	0.07	**24.4**	13.1%
IE	2.51	4.04	2.58	1.37	0.24	0.00	**10.7**	12.8%
LU	0.64	1.97	0.52	0.46	0.03	0.00	**3.6**	12.7%
SE	10.82	8.36	7.51	4.07	0.33	1.29	**32.4**	12.6%
PT	4.53	5.79	2.57	1.90	0.46	0.02	**15.3**	12.4%
BG	2.72	3.33	2.32	1.20	0.17	0.00	**9.7**	12.3%
FI	10.72	4.19	5.76	2.97	0.75	0.24	**24.6**	12.1%
LT	1.07	1.96	1.46	0.63	0.11	0.01	**5.2**	12.0%
HU	4.35	4.53	6.30	2.16	0.61	0.03	**18.0**	12.0%
HR	1.18	2.19	2.38	0.80	0.23	0.00	**6.8**	11.8%
PL	15.84	21.43	19.94	8.05	3.88	0.00	**69.1**	11.6%
SI	1.30	1.85	1.12	0.48	0.07	0.02	**4.8**	9.9%
AT	8.05	8.66	6.59	2.39	0.52	0.00	**26.2**	9.1%
RO	6.39	6.15	7.68	1.84	0.49	0.31	**22.9**	8.0%

All these were prerequisite for the EU Member States to work on resilience and energy efficiency strategies from which came the EPBD [4] and its most recent update in 2018, [5] forming an essential element of Europe's energy and climate policy.

The EU introduced the EPCs for the first time in the EPBD of 2002, as a mandatory requirement throughout all EU Member States for all new buildings, buildings to be sold, rented or renovated. In such a scenario, EU Member States have been developing policies and measures to reduce the actual energy use in buildings. This policy is amply explained in a recent study by the EU [19].

Most of the energy used in buildings aims at guaranteeing conditions of well-being, comfort and health for the buildings' occupants, tenants and society. This synergy creates the need and challenging endeavour to reconcile energy savings ambitions with the obligation to guarantee the conditions of residents growing up, living, working and learning in healthy indoor environments.

One notes that energy efficiency in itself is already an important component of the energy economy, and sometimes is considered as an additional energy resource, as already mentioned in Chapter one, because it helps to reduce the use of primary energy resources and achieve considerable savings.

The way buildings are designed, built and operated, offers tremendous potential for energy efficiency improvements along the entire energy value chain, especially if optimised with renewables. For this effect and in order to be in line with the EU directives, each Member State transposed them into national legislation to reduce the energy use in buildings and apply stringent requirements on the energy performance of new and renovated buildings, with a target to be nearly zero-energy as of 2021 for new and renovated buildings.

These buildings categorised as "dwellings" and "non-dwellings" are awarded a label at the design or end stages based on calculated or actual energy use. This label is the previously mentioned Energy Performance Certificate. The resulting certificate must be displayed in public authority buildings. The EPC reveals how efficiently the building is designed and operated, while the accompanying advisory report identifies potential improvements.

Figure 2-8 shows the current scenario of the total energy and building energy use across different countries in Europe taken from a recent study commissioned by the EU [38].

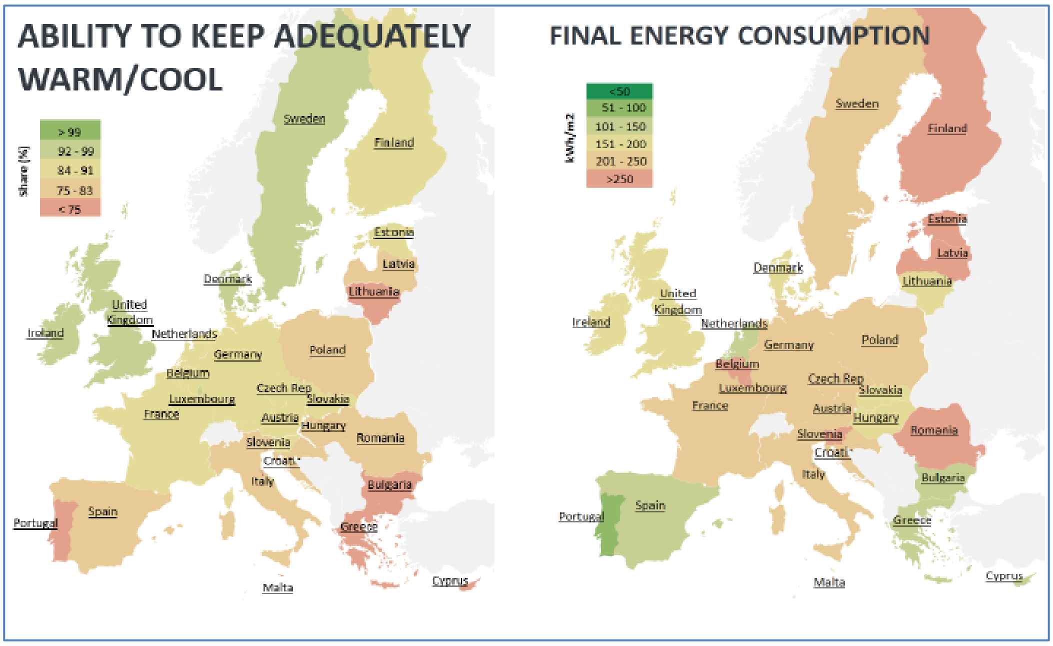


Figure 2-8: Building energy consumption across Europe [38]

From the colour's manifestation in Figure 2-8, it is quite evident that the total energy used in buildings is highly dependent on the yield and severity of the climate. This severity differentiates from predominantly heating load countries in the north which require more insulation to conserve the energy inside the rooms which is generally produced by heating plants, from predominantly cooling load countries in the south. Southern countries require other types of energy saving schemes such as shading to protect from the sun's beams of thermal radiation, which in turn transforms to a cooling load. In countries such as Finland, buildings need to be kept warm for nearly 87% of the time and have a high rate of primary energy consumption in the region of 250 kWh/m^2.yr.

One way to quantify the energy yield of a regional climate is to measure the number of yearly degree-days (DD). Concisely, degree days are a measure of how much (in degrees), and for how long (in days) the mean outside air temperature has fallen below or risen above a certain level (better known as base temperature), for which no heating or cooling is required to keep comfortable internal environmental ambient conditions. DD is a commonly used calculation in relation to the energy consumption required to heat or cool buildings.

For statistical purposes, base temperatures are generally taken as 15.5°C for heating while for cooling this is set at 18.5°C to make up for the time the building is cooled by natural ventilation and this energy removal is not calculated. However, the correct base temperatures, especially for cooling, depends on many other ambient variables, such as the amount of solar radiation falling on the facade, infiltration, ventilation rates, and moisture content. All these factors need to be catered for and calculated. Such a concept is essential and will be discussed in more detail in the following chapters.

2.1.5 Malta in a European context

The recent 2019 edition of the annual European Environment Agency (EEA) *Trends and projections in Europe 2019* report [33], which provides an updated assessment on the progress of EU Member States towards their climate mitigation and energy targets, states that Malta has fallen behind in all three areas of analysis. These are its energy efficiency; its renewable energy as well as its greenhouse gas emissions targets. The report has attributed this to the lack of ambition with regards to reducing or limiting energy consumption.

This report uses official data to look at the progress of Member States towards their objectives for the 2020 strategy with extended projections towards the 2030 strategy, using sectored coloured circles to indicate their key targets.

The colours indicate whether countries are considered to be on track or not with their 2020 climate and energy targets. In the report, orange represents the fact that the 2017 greenhouse gases emissions covered by the Effort Sharing Decision (ESD), were above the 2017 national ESD target. In the case of renewable energy, orange represents that the 2017-2018 share of energy from renewable sources (RES) in gross final energy consumption, was below the indicative level from the Renewable Energy Directive. In terms of energy efficiency, orange represents that the 2017 consumption in primary energy was above a linear indicative trajectory between the 2005 level and the 2020 national target.

In the case of Malta as shown in Figure 2-9, orange is used to dsiplay that both greenhouse gases emmisions and final energy consumption due to energy efficiency are below the expected targets.

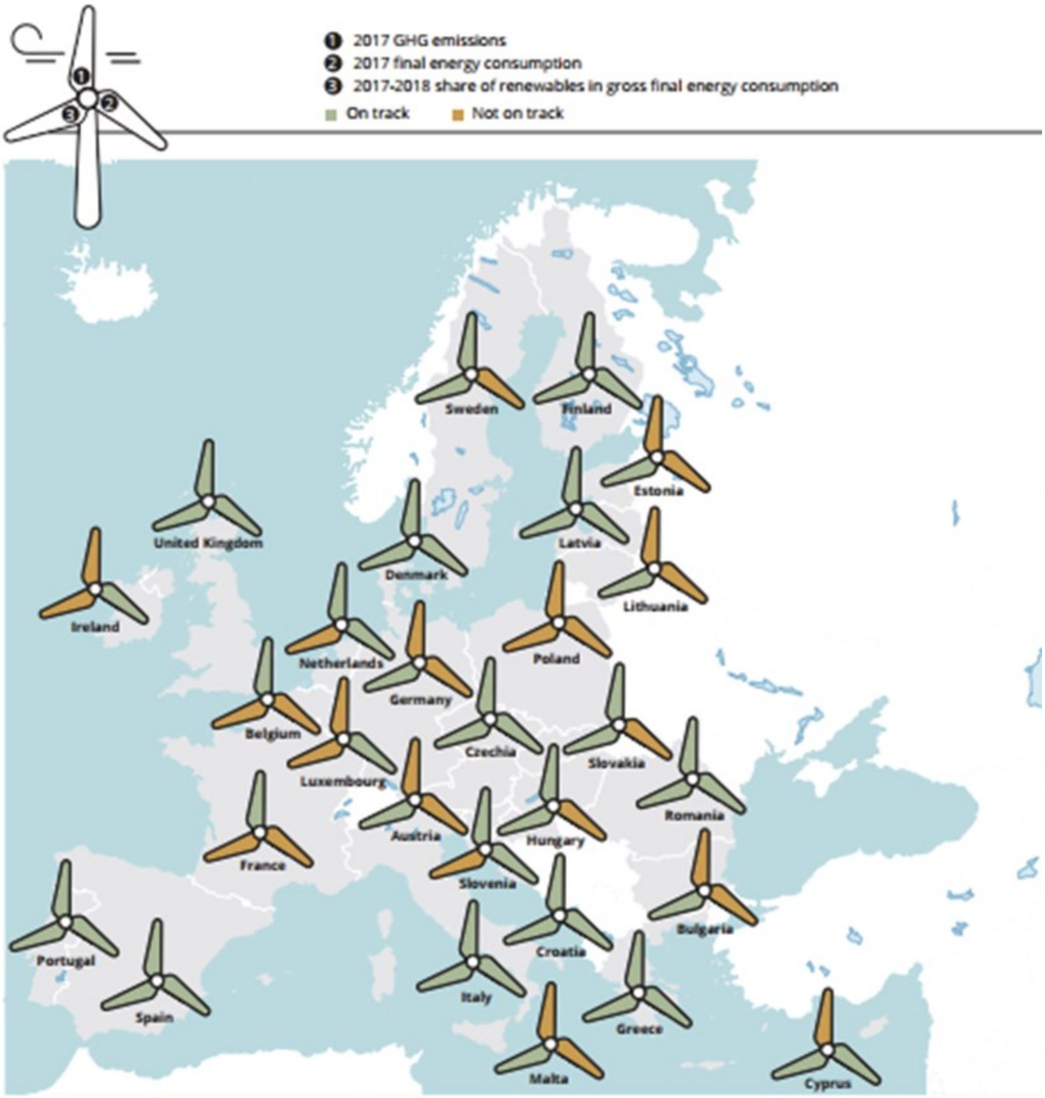


Figure 2-9: 2017 progress of Member States towards 2020 climate and energy target progess [33]

While this report is mainly based on national values taken as of 2017, it is to be noted that in the prevous reports issued in Eurostat News, for example the release on 4 May 2017 [39], Malta had the best peformace in the EU and registered a reduction of 18.2% in carbon dioxide emissions in 2016, also represented here in Figure 2-10. This came after introducing a better energy supply mix, which made use of substantial electrical supply from the newly installed a.c. interconnector between Malta and Sicily (Italy) in 2014.This was also the reason for the closure of the old, heavily polluting power station in Marsa in 2015. However, the CO_2 equivalent emissions then rose again in 2017, the year when the new gas power station was inaugurated [40].

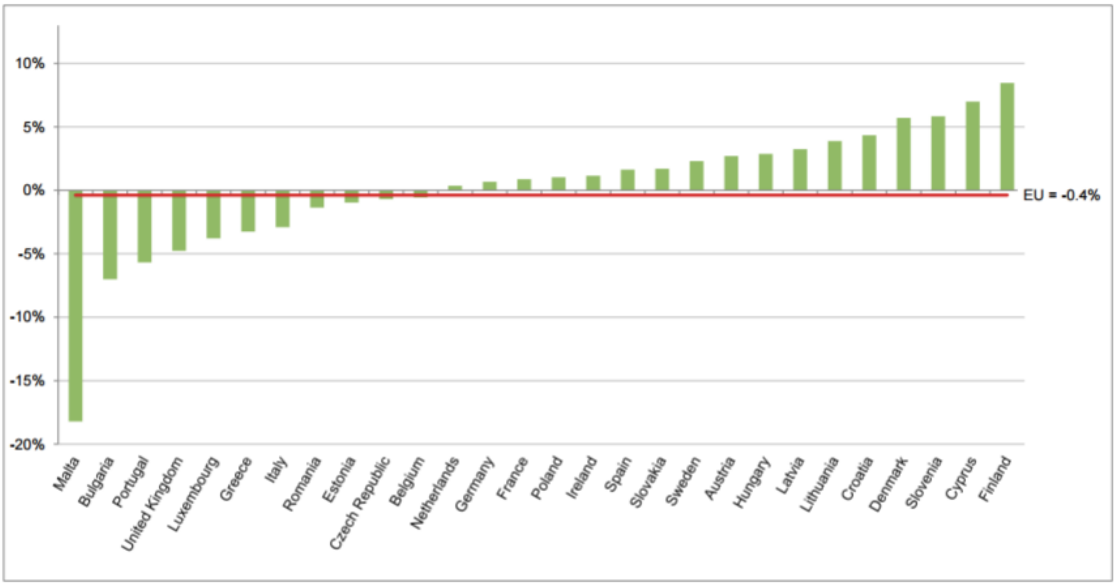


Figure 2-10: Estimated change in CO_2 emissions between 2015 and 2016 [39]

However future prospects for Malta do not look so bright. Recent analysis by the EU as illustrated in the *Trends and projections in Europe 2019* report [33], show that Malta did not reach the 2020 GHG emissions target by 26.5% and is lagging behind the GHGs and energy efficiency targets set for 2030 by 61.5% and 7.9% respectively, as shown in Table 2-2.

On the contrary, some Member States have already reduced their emissions to levels below their 2020 target, while for others including Malta, the gaps between observed emissions and national targets are widening.

Though in renewable energy Malta's deficiencies are not so grave considering that solar energy is abundant and the main option in such a small country, Malta's performance towards limiting GHG emissions and mitigating energy efficiency deficiencies to meet the 2030 targets are serious, and need to be addressed in the shortest time possible. One of the fastest methods to address these challenges is to reduce energy consumption and improve the energy performance of buildings.

Table 2-2: EU MS' progress to targets on greenhouse gas emissions, renewable energy and energy efficiency [33]

Member State	Greenhouse gas emissions				Renewable energy		Energy efficiency	
	Gap to ESD emission target (2017)	Gap to ESD emission target (2018)	Gap to 2020 ESD target (WEM)	Gap to 2030 ESD target (WEM)	Gap to 2017-2018 of RED trajectory (2017 RES share)	Gap to 2017-2018 of RED trajectory (2018 RES share)	Gap to 2017 FEC indicative linear (2017)	Gap to 2018 FEC indicative linear (2018)
	Percentage points (share of 2005 base-year emissions)				Percentage points (share of renewable energy in gross final energy consumption)		Percentage points (share of 2005 final energy consumption)	
Austria	-3.8	-3.0	-5.5	-20.2	2.3	2.6	-10.2	-8.8
Belgium	2.1	-0.4	-4.5	-21.7	-0.2	0.1	-7.5	-9.4
Bulgaria	-2.9	-3.0	5.0	-8.1	5.0	5.0	-9.4	-11.0
Croatia	11.6	9.7	19.2	-1.2	9.9	10.3	1.2	2.0
Cyprus	-1.8	-1.5	-8.9	-24.8	0.4	0.5	2.8	2.6
Czech Republic	4.6	2.9	6.5	-1.5	4.2	4.3	0.1	1.1
Denmark	5.2	3.6	0.5	-16.2	10.3	11.0	0.2	-0.2
Estonia	-5.1	-6.9	1.8	-24.8	6.7	5.5	-0.5	1.7
Finland	0.3	-1.2	-1.4	-15.5	6.3	7.1	4.3	4.8
France	1.4	2.5	-0.7	-13.3	-2.3	-1.7	-7.4	-4.9
Germany	-7.2	-3.4	-5.4	-16.2	1.7	2.9	-8.9	-8.9
Greece	21.9	23.3	21.0	9.1	2.8	2.9	10.3	9.3
Hungary	14.4	15.9	20.3	-3.0	3.4	3.7	-17.3	-21.2
Ireland	-6.3	-11.8	-14.7	-23.5	-0.8	-0.4	7.8	2.5
Italy	8.4	6.3	6.8	-6.1	5.4	4.7	8.4	6.7
Latvia	5.7	7.4	10.4	-2.0	1.6	2.8	9.0	6.5
Lithuania	-0.1	2.7	8.8	-14.0	5.6	4.1	-21.2	-25.2
Luxembourg	-0.1	-5.5	-5.2	-25.3	-1.1	1.4	2.3	-0.9
Malta	-22.8	-26.8	-26.5	-61.7	0.7	1.0	-5.5	-7.9
Netherlands	9.2	7.8	10.4	-3.6	-3.3	-3.0	4.1	4.3
Poland	-6.4	-9.0	-0.2	-20.9	-1.4	-1.3	-3.3	-4.2
Portugal	15.9	15.5	24.7	26.2	0.8	0.6	6.1	6.2
Romania	11.5	15.5	17.6	-12.5	2.6	3.0	24.3	25.0
Slovakia	16.5	14.9	19.7	-5.4	0.0	0.2	-13.8	-18.7
Slovenia	11.2	10.6	13.3	-0.2	-0.3	0.0	4.3	4.1
Spain	7.3	5.8	4.1	-9.7	1.5	1.7	5.2	2.3
Sweden	12.1	10.4	15.3	0.1	8.7	11.2	-0.1	-3.4
United Kingdom	6.8	6.7	10.7	-4.9	0.0	0.9	0.4	-1.8

Clearly, energy use in buildings (both residential and service buildings) in Malta is high and as shown in Table 1-1, reaches approximately 44% [14] of Malta's total final energy consumption. This is at par with the primary energy consumed by the transport sector. Therefore, the efficient use of energy in buildings becomes pertinent, if one is to meet the energy efficiency and carbon reduction targets, to contribute to sustainability, avoid non-compliance consequences and provide a better quality of life for present and future generations, where the social aspect cannot just be correlated in a straight-line equation to the financial burdens.

Moreover, the Cohesion Policy for Malta 2014-2020 [41] puts a priority on the need to shift to a low carbon economy, through the support for measures that foster energy efficiency, smart energy management and renewable energy in buildings. This is also the principal theme of Malta's 2030 National Energy and Climate Plan, which was recently endorsed and approved in 2019 [13].

Such measures cannot be implemented in a vacuum. Functional studies need to be made to ensure that energy efficiency measures are first implemented to achieve the highest impact possible on energy reduction and affordability.

As such the obligation to attain energy performance certificates (EPCs) is a step in the right direction, not only to conserve the ever depleting and finite fossil fuel resources and global warming effects, but also for financial and economic concerns to sustaining jobs in our industries.

2.2 Implementing the EU Energy Performance of Buildings Directive

2.2.1 The Energy Performance Certificate

The design of the Energy Performance Certificate scheme is a demanding task that needs to take into consideration specific characteristics of the building stock, as well as the expertise and everyday practice of the stakeholders involved in the real estate sector. The scheme also must fit in the existing legislative regime, including building codes and standards.

The choice and design of the assessment methodology are one of the significant challenges of the EPC implementation process. It needs to consider the differences between building types (new or existing, residential, commercial or public) and the specific circumstances (function, occupancy levels), and at the same time secure the comparability of energy performance levels.

There is a difference between an Asset Rating (AR) and an Operational Rating (OR), which both can be compiled in “As Designed” (calculated), or “As Built” (measured) stages. Usually, the calculated rating is considered a more expensive approach to obtaining energy performance information due to the time and effort needed for data collection on-site. However, it can be more useful for potential buyers and tenants of small buildings, as it defines the building’s performance rather than the occupants’ behaviour. On the other hand, the operational (measured) rating is more effective for large and complex buildings, and those with less frequent user turnover, since the use of the building is continuous across that category and therefore the operational rating would reflect both the user’s behaviour as well as the building’s performance.

According to the EPBD [5], the energy performance could either be calculated or based on actual measured readings on site to produce the energy performance and carbon emission ratings. Any energy performance certificates must also include an appropriate recommendations report. Those recommendations should ideally be either cost-optimal or cost-effective if implemented. The Directive does not exclude the use of other useful parameters such as the percentage of energy used from renewable sources in the total energy consumption or the actual energy consumption for non-residential buildings.

Another choice to make is the decision on the way energy performance rating is represented (i.e. energy level vs continuous scale), as well as the type of recommendations (i.e. standardised vs tailor-made). The final display of the EPC must include comprehensive and useful information in a user-friendly format that may have critical importance for the uptake of the mechanism by the market.

Another aspect of the design of the EPC scheme is linked to quality assurance systems. For example, the choice of sampling and validation methodologies for the statistically significant percentage of EPCs regarding the quality check. This check may vary (e.g. random sample from all EPCs issued or random sample of the assessor's certificates). It is interesting to note that Annex II of the EPBD provided a recommendation on this matter, but the final decision was left to the Member States. As stated in the IEA 2010 report [2] the design of the EPC scheme also considers the efficiency of the organisation or agency responsible for its maintenance and the securing of necessary resources (i.e. administrative, technological, institutional and financial) towards further implementation.

In short, the EPCs have become a powerful tool to create a demand-driven market for energy efficient buildings, since it has incentivised sellers in many Member States who are including a factor related to the energy consumption and efficiency of a building, in their estimated costs.

A recent study commissioned by the UK Royal Institution of Chartered Surveyors (RICS) [42] showed that the existence of an energy performance certificate could impact the value of buildings by up to 2.5%. To this effect, initially in December 2010, the Building Performance Institute Europe (BPIE) released a critical report [43] which investigated the success factors and barriers along the design and implementation process of the EPCs schemes in twelve selected EU Member States where this was being implemented.

The research concentrated on the analysis of the success factors and challenges of the design and implementation processes:

a. the basic implementation approach;
b. the use of certificates;
c. public acceptance by consumers and professional stakeholders;

d. the cost of certificates;
e. administration/registration;
f. quality control.

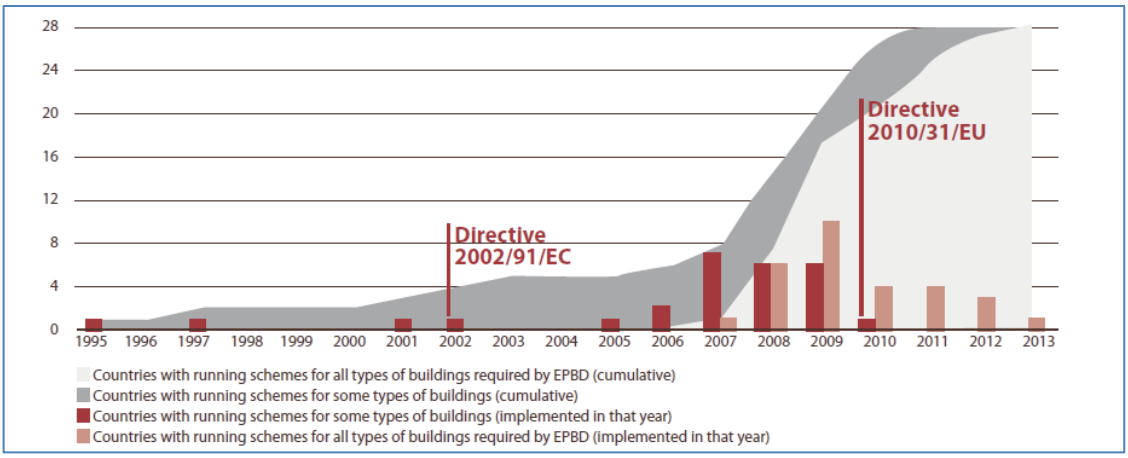


Figure 2-11: Implementation status of the EPC systems across Europe up to 2013 [44]

On the other hand, Figure 2-11 taken from EPC statistics across Europe [44], shows that by 2013, all 28 Member States had introduced EPC legislations and processes all. Thus, 28 EPC methodologies exist. With so many active processing methods, such certificates vary significantly across Member States in terms of scope and available information. In some cases, this may result in limited reliability, compliance, market penetration or acceptance by the users. Recent analysis in the 2019 *EPBD Key Implementation Decisions* [45] states that around six million EPC certificates are issued every year, with the UK leading with more than 20 million EPCs in total as shown in Figure 2-12. The UK has the most EPCs per capita with 0.31, followed by Belgium, Ireland, Denmark and Portugal.

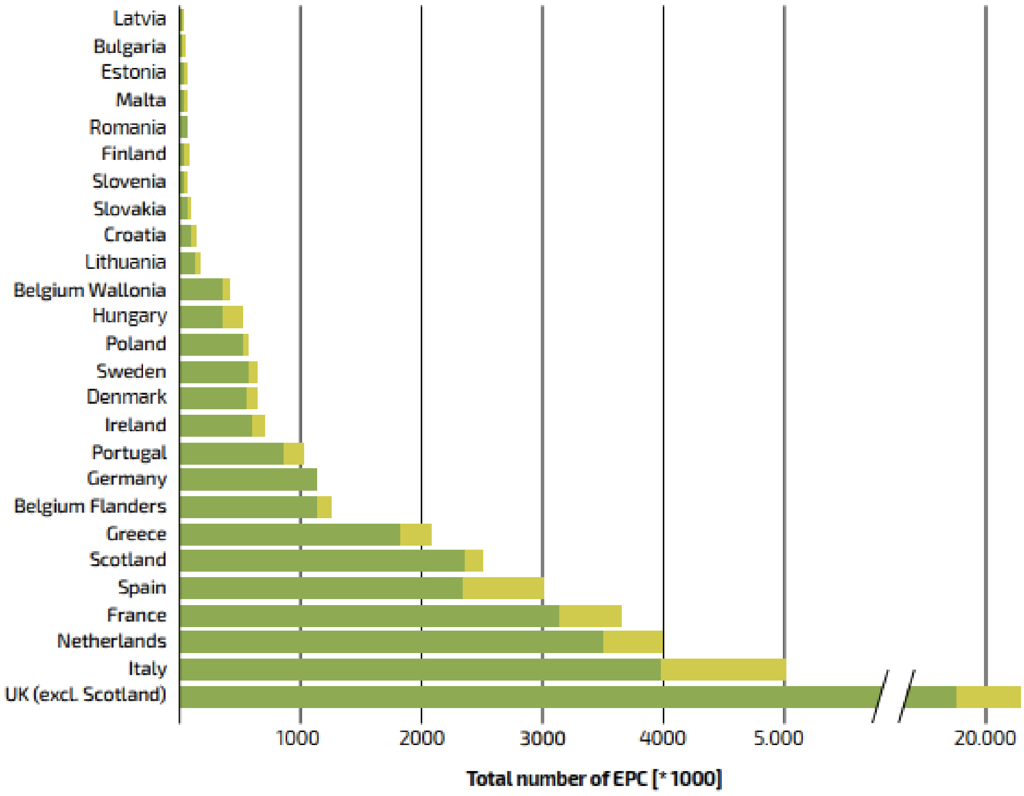


Figure 2-12: Number of EPCs registered per country/region with yellow part representing recent submission [46]

The EPBD 2010/31/EU [4] provides guidance for Member States regarding the EPC calculation methodology. In fact, its Annex I states “that the energy performance of buildings can be evaluated on the basis of the calculated (asset rating) or actual energy consumption (operational rating)”. Among the 28 EU Member States, 12 have adopted the methodology exclusively based on calculated energy consumption. In other countries, both the actual and calculated energy consumption are used as shown in Figure 2-13. Malta uses the calculated methodology only.

Figure 2-13: Implementation of asset and operational rating methodologies in the EU [47]

Generally, the visual presentation for EPCs is similar because it shows the general characteristics of the building and the assessed label class on the first page. Some examples of the first pages for EPCs in Denmark, Ireland and Austria, are shown in Figure 2-14 below.

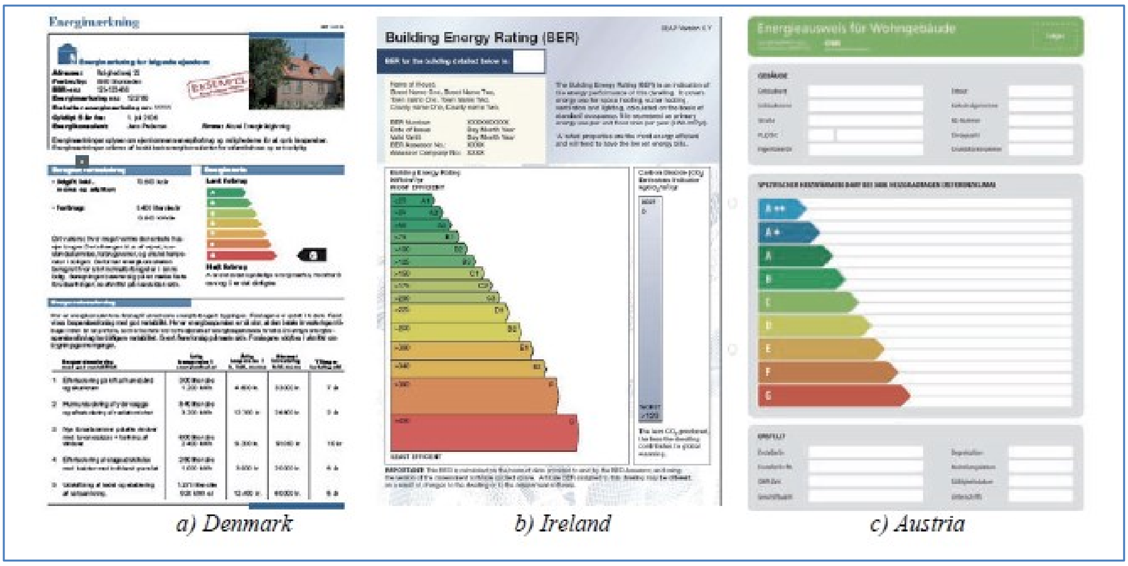


Figure 2-14: EPC certificates in Denmark, Ireland and Austria. [43]

In 2018, the EPBD 2010/31 [4] was amended and updated as (EU) 2018/844 [5], with a direction to go for smarter buildings and more emphasis on renovation, for which a special conference was held in Malta on 14 February 2017, on the initiative of the Concerted Action Group Committee [48]. In short, this amendment set out that: EPCs shall be determined on the basis of calculated or actual energy use and shall reflect typical energy use for space heating, space cooling, domestic hot water, ventilation, built-in lighting and other technical building systems. Member States have to describe their national calculation methodology following the national annexes of the overarching standards, namely ISO 52000-1, 52003-1, 52010-1, 52016-1, and 52018-1, developed under European Standards mandate M/480 [49].

2.2.2 Local energy certification of buildings (EPCs)

Under this regulation, the Energy Performance Certificates (EPCs) were introduced in Malta in 2009 with Legal Notice 261 of 2008 [50], which was later updated by Legal Notice 376 of 2012 [51] and by Legal Notice 47 of 2018 [52]. By 2019, some 48,000 EPCs have been lodged on the Building Regulation Office (BRO) database.

These buildings categorised as “dwellings” OR “non-dwellings” are awarded a rating at the design or as-built stages known as the Energy Performance

Certificate (EPC), based on the EU Directive 2010/31/EU on the energy performance of buildings recast.

These regulations promote the improvement of the energy performance of buildings within the European Union, considering outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness. As of January 2, 2009 (for dwellings) and June 1, 2009 (for other buildings), an owner or his agent had to obtain an EPC in the form prescribed by these regulations when a building is being constructed, renovated, sold or rented out.

Originally the 2006 Legal Notice 238 introduced the minimum requirements for all buildings as detailed in Technical Document F [16]. These minimum requirements tackled various aspects ranging from construction of the building envelope to lighting systems and other technical components. These included thermal insulation on roofs, limits on window sizes depending on solar gains, improved glazing, the imposition of power and timing regulating controls on heating and cooling systems, the conservation and re-use of rainwater and increased awareness on the benefits obtained from renewable energy sources (RES). This document F also established the thermal transmissivity (U-value) of walls that was adopted to reflect the local practice of building double walls with an inner and outer 180 mm leaf constructed with stone blocks and separated by a cavity.

Moreover, given Malta being a predominantly cooling load country, these minimum requirements introduced limits for the size and positioning of glazing to reduce the solar gains.

The EPCs are the product of the certification process and include reference values based on the Asset Rating (AR) of the building. If the building is not yet constructed and/or finished, it can be issued as an Asset Rating with a “Design” scope. On the other hand, if the building is already constructed and in use, it can be issued as an “As Built” scope. The certificate is valid for ten years from the date of its first issue. The real benefit of any EPC lies in the cost-effective recommendations, which are provided by the assessor, but does not necessarily need to be implemented.

Currently, Malta has two types of AR calculation methodologies. One is for the Energy Performance of Residential Dwellings in Malta (EPRDM) [53], which considers the climate and steady-state net annual energy required for space heating and cooling, water heating, lighting, and ventilation. It also considers the energy gained or generated from renewable energy systems and the use of second-class water to save energy. One must note that more than 60% of Malta's potable water comes from seawater reverse-osmosis plants that require intensive energy processes [54]. This transforms the high salinity clear seawater from around 35,000ppm to below 1,000ppm, to meet EU legislations [54]. EPRDM calculates the annual values of delivered energy consumption (energy use), primary energy consumption, and CO_2 emissions.

While for non-residential buildings, a different AR calculation methodology using the Simplified Building Energy Model for Malta SBEM-mt is applied [55]. This SBEM was adapted from the UK's similar national methodology calculation tool using building zones for the calculations in which identifiable standardised activities take place. It also compares the carbon emissions of the actual building to those of a 'reference building', which is a similar building but is subjected to a specified built 'improvement factor' of 20% to those criteria as given in the first Technical Document F of 2006. After which a percentage ratio of yearly modelled building to reference building carbon emission rating is calculated. In SBEM-mt, monthly weather data files are used.

Duly qualified engineers and architects must follow and successfully undertake a period of training which is approved by the local Building Regulation Office (BRO) on the use of software to qualify as assessors.

2.3 The EPCs for non-residential buildings

2.3.1 The Simplified Building Energy Model for Malta (SBEM-mt)

In Malta, the AR EPC for non-dwellings is calculated based on the SBEM software of the Building Research Establishment (BRE) of the United Kingdom [56]. The BRE has adapted the software for the BRO in Malta to include the Maltese climate and some essential elements such as space cooling, as well as a local building material database, named SBEM-mt v. 4.2c software programme.

The purpose of SBEM-mt is to produce consistent and reliable evaluations of energy use in non-domestic buildings, and although it may assist in the design process, it is not intended to be used as a design tool. Its manual specifies that the SBEM-mt should not be used for making strategic design decisions.

SBEM is a computer program that provides an analysis of a building's energy consumption by calculating the monthly energy use and carbon dioxide emissions of a building on a given description of the building geometry, construction, standard use schedules and HVAC, domestic hot water and lighting equipment. It was initially based on the Dutch methodology NEN 2916:1998 (Energy Performance of Non-Residential Buildings) [57] and has since been modified to comply with current CEN standards. Details of the calculation method, the algorithms used and the assumptions made are provided in the SBEM Technical Manual [55]. SBEM makes use of standard data contained in associated databases and available with other software known as its interface iSBEM.

A more in-depth look at SBEM UK offers a revised and frequently updated version, in line with revisions to UK Approved Document L2A [58] to include additional functionalities. The current version used in the UK is version v5.6.a – and can be used both for demonstrating the building’s compliance with the L2A standard as well as for generating EPCs [59]. However, the local SBEM-mt has only one version, the 4.2c and has never been updated since 2011.

SBEM-mt consists of a calculation methodology and an Energy Performance Certificate Generator (EPCgenMT) and calculates the energy demands for each space or zone in the building according to the activity within it. Different activities may have different temperatures, operating periods, lighting standards, besides other factors. SBEM-mt calculates heating, cooling energy, hot water and lighting demands by carrying out an energy balance based on monthly average weather conditions. These demands are combined with information about primary cooling and heating plant efficiencies in order to determine the energy consumption. This requires information from the following sources, shown in Table 2-3.

Table 2-3: Calculation basics for Malta energy performance Certificate [55]

Information	Source
Building geometry such as areas, orientation, etc.	Assessor reads from drawings or direct measurement.
Weather data	Internal database (based on the year 2010)
Selection of occupancy profiles for activity areas	For consistency, these come from internal locked activity database templates; the assessor selects the appropriate building type and activity from the database for each zone but cannot change the activity schedules.
Activity assigned to each space	The assessor selects the appropriate activity for each zone based on provided plans or after carrying out a site visit to identify the activities for each zone.
Building envelope constructions	The assessor selects from internal construction and glazing databases. The assessor can also define new constructions and use them where necessary.
HVAC systems	The assessor selects from internal databases or inputs parameters directly, based on the surveyed data on site.
Lighting	The assessor selects from internal databases or inputs parameters directly, according to the installed systems.

Once the above inputs are finalised the assessor needs to:

a) enter general information about the building, the owner, and the certifier/assessor details;
b) build up a database of the different forms of constructions and glazing types used in the fabric of the building;
c) after zoning the building (on the drawings), create the zones in the program and enter their basic dimensions, along with the air permeability of the space;
d) define the envelopes for each zone, i.e. walls, floor, ceiling, etc. defining the envelopes' areas, orientations, the conditions of the adjacent spaces, shading and the constructions used;
e) Enter the areas and types of glazing or door within each envelope element including any windows/roof lights or doors;
f) define the HVAC (heating, ventilation, and air conditioning) systems, the HWS (hot water systems), and any SES (solar thermal energy systems), PVS (photovoltaic systems), wind generators, or CHP (combined heat and power) generators used in the building;
g) define the lighting system and local ventilation characteristics of each zone, and assign the zones to the appropriate HVAC system and HWS; and
h) run the calculation to generate an EPC.

In SBEM-mt, the building engineering services systems, zones, envelope elements, windows, and doors are all referred to as building objects. In a schematic layout Figure 2-15 [55] shows each of these building objects and demonstrates how they are linked together so that SBEM-mt can calculate the energy consumption of the building.

Building object	Key parameters needed to define this building object	Object(s) to which it needs to be linked	Where it is defined in iSBEMmt
Zones	Dimensions, activity type, details on lighting, heating, and ventilation strategy.	HVAC and HWS	Geometry form > Zones tab and in the Building Services form > Zones tab
Envelope elements	Type of envelope (wall/floor/roof), area, orientation, construction type, thermal bridges, perimeter length, and condition of adjoining space.	Zone	Geometry form > Envelopes tab or the Geometry form > Zones tab > Quick-Envelopes sub-tab
Windows	Dimensions, glazing type, thermal bridges, shading system, frame factor, aspect ratio, and whether it is a display window or not.	Envelope element	Geometry form > Windows & Rooflights tab or the Geometry Form > Zones tab > Quick Envelopes sub-tab
Doors	Area, construction type, thermal bridges, and type of door.	Envelope element	Geometry form > Doors tab
HVAC	System type, heat source, fuel type, further details on efficiencies, duct leakage, specific fan power, and controls.	Zone	Building Services form > HVAC systems tab
HWS	Generator type, fuel type, details on efficiency and whether it is a storage system.	Zone	Building Services form > HWS tab
SES	Dimensions, orientation, inclination, storage.	HWS	Building Services form > SES tab
PVS	Dimensions, orientation, inclination and type.	-	Building Services form > PVS tab
Wind generator	Terrain type, dimensions, and power.	-	Building Services form > Wind generator
CHP generator	Fuel type, details on efficiency, building heat and hot water supplied, and thermal and electrical efficiencies.	HVAC	Building Services form > CHP tab
TSC	Type, operation, control type, absorptivity, and design air flow.	Zone and Envelope element	Building Services form > TSC tab, Geometry form > Envelopes tab, and Building Services form > Zones tab

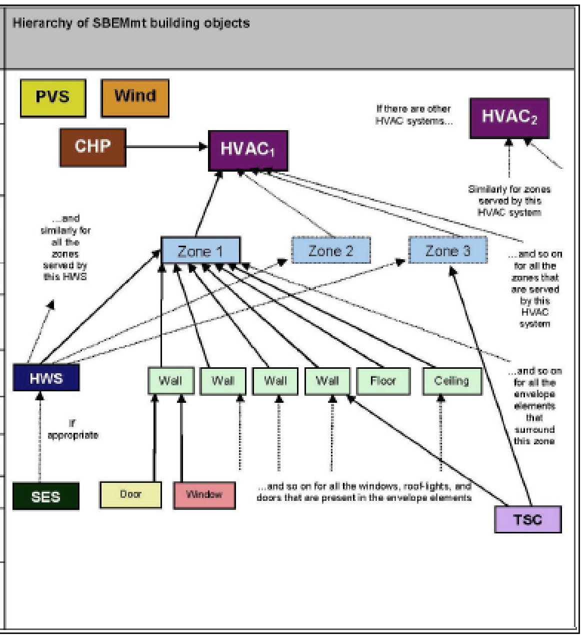


Figure 2-15: Definitions and Key parameters of SBEM-mt Building Objects [56]

2.3.2 The reference building and the EPC grade

The EPC AR of non-dwellings is a percentage comparison between the Carbon Dioxide emissions from the actual building, compared to the Standard Emission Rating (SER) emitted from a Reference Building. The Reference Building is the same building as the actual building with similar geometry but built and supplied with energy systems as defined in the first version of Minimum Energy Performance Requirements of Technical Document F of 2006 [16], with a 20% improvement imposed on the SER to cater for efficiency advancements since that year. In short, the reference building:

a) has the same building services strategy but with its central heating and cooling plant and luminaires selected with seasonal operational efficiencies as those dictated in Document F of 2006;
b) has the same size and shape of the actual building (but glazing area depends on the set minimum energy requirements);
c) each space contains the same activity as the building under consideration, and therefore activity schedules, including set point temperatures and other parameters are as actual;
d) same orientation and weather data file;

e) has the outside thermal energy transmittance (U- values), as those dictated in Document F of 2006;
f) space heating and cooling (cooling only when needed to avoid overheating at temperatures above 26.5 °C, and
g) has specific fan power (SFP) as dictated by best practices benchmarked categorised building, where relevant.

These two calculations for the unit CO_2 emissions from the Actual Building and the Reference Building are run concurrently on the same programme, and a grade is given for the AR based on the percentage between the BER against the SER, as shown in

Table 2-4 below:

Table 2-4: Asset Rating and energy bands [55]

$$AR < 0 \Rightarrow A^{+}$$
$$0 \leq AR \leq 50 \Rightarrow A$$
$$51 \leq AR \leq 100 \Rightarrow B$$
$$101 \leq AR \leq 150 \Rightarrow C$$
$$151 \leq AR \leq 200 \Rightarrow D$$
$$201 \leq AR \leq 250 \Rightarrow E$$
$$251 \leq AR \leq 300 \Rightarrow F$$
$$300 < AR \Rightarrow G$$

For the electrical generation, the carbon emission factor for the SBEM v4.2c is set at 0.878 kg/kWh [55]. However, following the significant upgrade to the power generation facilities in Malta using liquefied natural gas and the commissioning of the electric interconnector between Malta and Sicily, the overall PEF to produce electrical energy is currently 2.0, as published by the local Energy and Water Agency [60]. The PEF is the ratio of the energy content of fuel burnt to generate electricity and the actual end-use electrical energy. In Malta, it includes fuels used by conventional power generation plants; electricity generated by renewable energy sources (namely from photovoltaics and waste to energy plants) as well as the imports of electricity through the interconnector.

This new PEF contrasts heavily with the old value of 3.45 that is used in SBEM-mt v4.2c. Moreover, such a change calls for a future upgrade of the software’s inbuilt values.

2.4 Limitations of the calculated asset rating (AR) methodology at design and built stages

SBEM-mt may be an excellent tool to calculate the monthly energy gain or lost for a building, taking into consideration weather data, activities, occupation and associated internal gains but its calculation for AR whether at design or as-built stages does not consider the complexity and integrity of how building services engineering are designed, selected and operated, such as the quantity and capacity of the main cooling and heating plants, their electrical power configuration, water or air circuitry, capacities of auxiliaries, configuration for resilience, modularity and flexibilities etc. which are essential for the asset rating value of the building itself but more importantly for the energy used during its operation. Moreover, the fact that SBEM-mt only uses average monthly values for weather conditions and average annual factors for the building envelope (e.g. U-values, shading factors, reflectance) and for the building energy systems (e.g. SCOP, SEER, hot water boiler efficiency, etc.), implies that all peak and low operation during the year is not captured. This limits the program’s capacity.

Furthermore, SBEM-mt methodology does not compare the projected energy of the building to some form of a fully well designed actual operational building, generally known as the benchmark building, such as those listed in UK CIBSE TM46 - Energy Benchmarks [61], but it rather compares the building to a similar physical construction that is conforming to Technical Document F with a 20% improvement of its SER. In other words, the SBEM-mt simply states to what extent the building matches the minimum energy performance regulations.

On the other hand, if one is to compare the energy rating of a building to a benchmarked building, then the potential of improving energy performance takes a new dimension – that of real energy savings rather than theoretical estimates. This is ultimately the goal of the EU to achieve carbon neutrality by 2050 based on real terms.

Notwithstanding, the SBEM-mt software has been used to generate the 2018 cost optimal levels for seven non-residential buildings [62]–[67], as shown in Table 2-5.

Table 2-5: Proposed cost optimal and nearly-zero energy levels for a selection of different non-residential buildings, as extracted from different reports [61-66]. Values between brackets are delivered (end-use) energy

Building	Proposed cost optimal primary energy levels (kWh/m².year)		Proposed nearly zero-energy primary energy levels (kWh/m².year)	
	New	Renovated	New	Renovated
Homes for the elderly	736 (214)	747 (217)	703 (209)	715 (213)
Hotels	786 (228)	901 (284)	757 (219)	890 (281)
Restaurants	1534 (445)	1595 (462)	1534 (445)	1595 (462)
Schools	369 (107)	375 (109)	233 (89)	265 (99)
Shops	775 (225)	887 (257)	556 (225)	667 (257)
Sports complexes	618 (179)	638 (217)	526 (172)	545 (177)
Offices	464 (135)	Not available yet	405 (117)	Not available yet

In order to overcome the challenges of financing energy efficiency measures in non-residential buildings, the EPCs per se are an excellent supporting tool, as has already happened in some Member States such as the Netherlands. However, in the commercial sector, the EPC as an AR is often not regarded as an adequate investment instrument by financing institutions due to its limitation in reflecting the actual operational performance [68].

In Malta, as in all the other Member States, the trends of building operational energy consumption is rising as shown in Table 2-1, reaching 44% [14] of the total energy consumption in Malta, however EPCs are not as popular. They are only requested because of legal requirements. However, as a result of the awareness to reduce operational costs as well as lowering the greenhouse effects, users of non-residential buildings and financers have started becoming interested in achieving a good EPC rating. These entrepreneurs hear a lot about low energy efficient buildings and subscribe to investments that rate the design of the building. Nevertheless, quite often the EPCs do not match the actual energy consumption when the buildings come in use, as there seems to be a mismatch with the measured readings.

If a Performance Gap exists, this could be the result of limitations already highlighted in the previous sections as well as the lack of information on behalf of building engineering services, such as data requirements listed in UK Chartered Institute of Building Service Engineers (CIBSE), CIBSE Guide F [69] Energy Efficiency in Buildings or CIBSE TM 54 – Evaluating Operational Energy Performance of Buildings at the Design Stage [70].

However, as indicated in CIBSE AM-2015 AM11 Building Performance Modelling [71], the UK's SBEM, the original model which SBEM-mt is generated from, is more of a compliance software. SBEM UK checks if a building has been built to specific standards and regulations, namely the prevailing minimum energy performance requirements in that country, which in the case of the UK, refers to their Building Regulations Office Approved Document Part L2A [58].

In fact, Figure 2.16 shows examples of software and tools available and gives guidance on when they can be used and what they could be selected for. The diagram includes design stages, from concept to detailed, and various design questions covering overheating, natural ventilation, plant sizing and compliance. However, these are not exhaustive lists of the design problems or software solutions. SBEM is only listed to show if the design of the building complies with Part L regulations and does not assign the required energy use intensity.

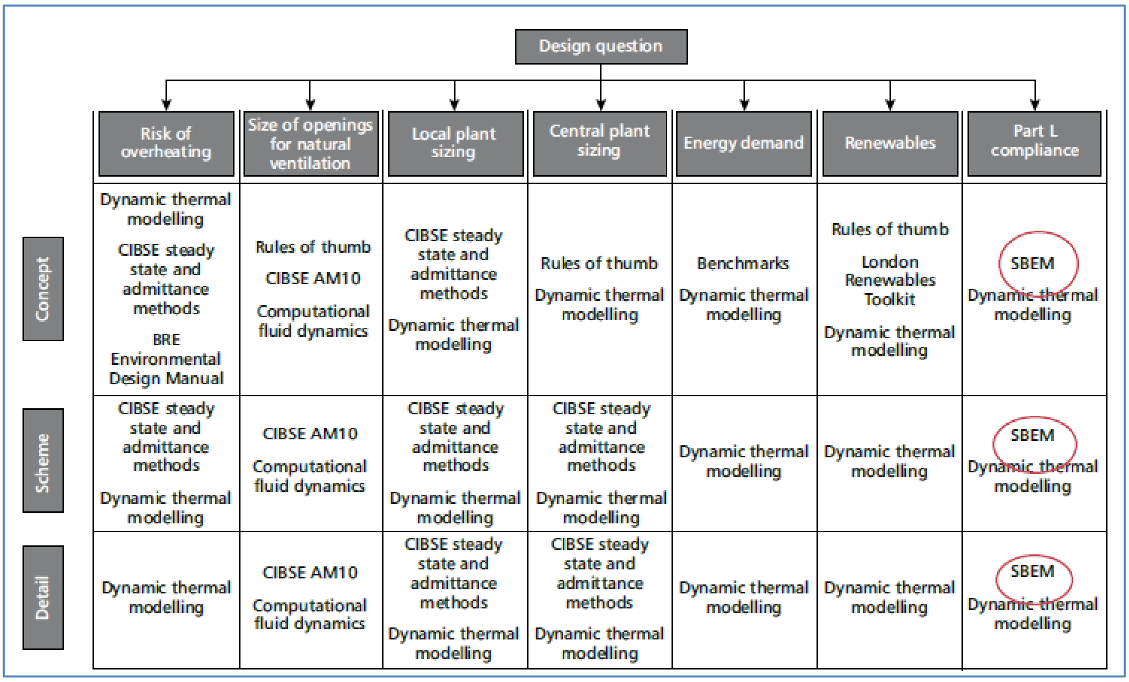


Figure 2-16: Examples of part design questions and suggested type of software to apply at various design stages [71]

2.5 The Performance Gap

Research into the energy performance of buildings has been ongoing for many years, but more recently focus was given on the issue of whether the EPC reflects actual energy consumption in different buildings. The ultimate aim of the EU is to achieve carbon neutrality by 2050 and this has to be achieved based on real values, both in terms of reduced carbon emissions, reduced fossil fuel dependency and increased renewable energy contribution. It was found that a performance ‘gap’ does exist between the outcome of energy performance certificates and actual energy consumption. That is one of the main reasons why the new update of the EPBD (EU) 2018/844 proposes EPCs that are based on Operational Rating (OR).

In fact, the EPBD allows Member States to use any of two methods for determining the energy performance rating of buildings. The first is known as the Asset Rating (AR) based on either *design* or *as-built* approach and the second is Operational Raing (OR). AR uses software and standard input data to simulate the energy performance of a building that is still to be built, at its intial design stage or at the built stage for an existing building. While the OR, depends on the analysis of actual energy consumption within an existing and fully operational building, and this analysis usually considers a minimum of three years of data. Therefore, when one speaks about a performance *gap*, it is essentially, a variation in the results as calculated by a software, i.e. its AR, and as calculated from actual energy consumption i.e OR.

The UK has been working on this issue for a number of years. In fact, the *CIBSE TM54 Evaluating Operational Energy Performance of Buildings at the Design Stage* [70], has been developed and used to evaluate this gap between the predicted and measured energy usage. The aim is to reduce the gap as much as possible; thus putting more value on the relevance of energy conservation in the construction of smart and practical buildings.

In his paper, De Wilde et al. [72] has identified several strategies that can be explored to study and came up with a calibration methodology to bridge this gap. Menezes et al. [73] have used the EPC as produced from software and the actual energy consumption of different buildings and came up with models that can predict the performance of the building to within 3% of its actual consumption. Furthermore, Choudhary [74] has identified certain factors that could play an essential role in determining the extent of the gap between the predicted and actual energy performance of buildings, which includes the area, the use of the building and even whether the building is situated in a city or on its outskirts. Heo, et. al. [75] looked at the problem from a different angle, whereby they incorporated sources of uncertainties, such as physical properties and equipment performance and highlighted the fact that other dynamic uncertainties need to be considered, such as the ageing of equipment.

In the applied energy symposium on low carbon cities and urban energy systems, held in Shanghai, China (June 2018), Sun Dongmei from the Shenzhen Institute of Building Research presented a paper [76] to establish the best scientific and rational method for benchmarking non-residential buildings, Results showed that, "multiple regression analysis" and, "cumulative probability of energy consumption ratio" is more reasonable and accurate than the, “statistical characteristics method based on building sub-classification", as shown in Table 2-6.

Table 2-6: Advantages and disadvantages of different energy consumption benchmarking methods [76]

Methods	Advantages	Disadvantages
Statistical characteristics method based on building sub-classification	• The method is very simple; • Only need a little building information.	• The energy consumption benchmark has not taken into account all major factors, such as weather, operations, etc., which will lead to unreasonable results; • It cannot be used for comparison of similar buildings across the whole country
Probability method based on building sub-classification and the revision of actual *EUI*	• The method is very simple; • Only need a little building information; • Some operating characteristic parameters are used to correct *EUI*, which reflecting individual differences	• The revision of actual *EUI* has not considered all the main factors, making the comparison of similar buildings not under identical conditions, which may lead to unreasonable situations. • It is cannot be used for comparison of similar buildings across the whole country
multiple regression analysis method	• The standardization of building energy consumption benchmark takes into account all major factors (weather, size, operations, etc.), which is the most just and accurate method; • Building in the national range can be compared	A large number of building operation parameters are required to collect, which increases the workload and difficulty of data collection.

This study concluded that although the statistical method based on building classification is the simplest, it is not sufficiently accurate. However, the Multiple Regression Analysis is the most accurate method, but it needs a large sample of various categorised data sets with different variables such as area, operating schedule, occupancy etc.

Moreover, E Burman et. al., in their comparative study on the best energy consumption benchmark [77], between bottom-up or top-down approaches for non-domestic building, concluded that although both approaches can improve design practice and operation, the bottom-up methods are more focused on the building specific contents. This method aims to device a yardstick for energy performance based on a theoretical analysis of the building. On the other hand, top-down methods initiate improvements by ranking them against a good practice benchmark.

Moreover, since the publication and advertising of EPCs have become mandatory, the public is frequently encountering this publicity and is becoming aware of the energy indicators and related information. Besides this being one way to boost energy efficient awareness, recent studies show that under similar location conditions, energy efficient buildings sell or rent faster and at a better price than buildings with poor energy efficiency performance.

As building energy certification systems have now been implemented for a number of years and energy performance data has been collected in databases, countries have been making various attempts to evaluate their influence on actual energy consumption, and on real estate markets, with the aim to assess the efficacy of certification as a policy tool for reducing energy consumption in the building sector.

Fuerst et al. [78] investigated the relationship between UK EPC ratings and sale prices of dwellings, and suggested that energy efficiency labels have a measurable and significant impact on housing prices in England. In the case of the Netherlands, Brounen, Kok and Menne [42] have shown that an identical house with an A-rating retails for about 12% more than a house with a G-rating.

Although the real-estate market, like most other sectors, has been affected by the recent economic crisis, this tendency has been confirmed in more recent research work on buildings in an initial study commissioned by the EU [79] and on other work carried out in this field by F. Fuerst et. al [80].

Furthermore, when looking into what Member States have done to increase energy efficiency in non-residential buildings, many countries have introduced authoritative building energy policies to achieve CO_2 emission reduction targets [81], [82]. As such, building energy codes and minimum energy performance standards have been enforced and regularly strengthened for new and existing buildings.

Also, many countries set targets for zero energy buildings to reduce greenhouse gases (GHG) in the building sector. Moreover, over the last few years, energy performance certification has also been introduced with useful good practice benchmarks to the commercial and residential building sectors, as a vital policy instrument that can assist governments and tenants in reducing energy consumption in buildings [83]. This documentation provides customers with information on buildings, either concerning achieving a specified level of energy performance or in comparison to other reference buildings [84].

Since the European Union's Energy Performance of Buildings Directive (EPBD) in 2002 created a common framework to improve the energy performance of buildings [83], mandatory energy certification policies have been enacted and implemented in member countries over the past decade. In fact countries such as Denmark, had launched mandatory energy performance certification systems for commercial and residential buildings as early as 1992 and 1993, respectively, which was a decade before that initiated by the EU in 2002 [83].

Majcen et al. [85] examined actual and calculated household energy consumption and identified their discrepancies concerning the targets set for reductions in energy consumption for the residential sector in the EU and the Netherlands.

By systematic mapping of 79 papers from thirteen application domains using data analytics on existing EPCs, O. Pasichnyi et.al [86] reveal increases in the number and complexity of studies and advances in applied data analysis techniques. For the case of Sweden, the proposed data quality assurance method based on six validation levels was tested using four samples of EPC dataset . The analysis showed that EPC data can be improved through adding or revising the EPC features and assuring interoperability of EPC datasets. In conclusion, EPC data have wider applications than initially intended by the EPC policy instrument, placing stronger requirements on the quality and content of the data.

Energy Performance Certificates need a degree of consistency if the information provided by these documents are to be used for applications designed to improve the energy efficiency of the building stock of a country. D. Jenkins et. al. [87] demonstrated through investigations that the level of quality and outputs, from a standardised energy assessment can be variable. Remarkably, different assessors evaluating the same property gave different results, which confuse tenants on the appropriate course of action to reduce consumption. Using the results of studies conducted by the authors and from others, qualified databases gave recommendations to what this form of energy assessment should be used for, and whether improvements can be made in the future, as areas of policy look to reflect the recorded energy performance of buildings through a range of policy vehicles.

On the other hand, some categories of non-residential buildings such as hospitals use a lot of sophisticated medical equipment, which are constantly being improved to consume less energy. However, one has to understand that this is a particular specific benchmark and as highlighted by P. Morgenstern et al [88] after conducting a number of recent studies on hospitals all-over Europe the UK Guide “F” benchmark for this categorised building needs to be updated. In fact, she has also pointed out that in view of the high energy consumption in certain types of such departments, operating theatres, nuclear medicine and imaging, hospital energy benchmarks need to be resolved for as specific areas or departments as possible.

In fact, and as shown in Table 2-7 for this particular category in the UK there are three systems of benchmarking that cover National Health Services (NHS) properties ie a national energy target for the NHS Trusts of 413–488 kWh/m^2 per year, the EnCO2de [89] and the BRECSU [90], which still use CIBSE Guide F [69] as their reference. Moreover, as mentioned in section 2.7, CIBSE has just launched on-line beta version of Digital Benchmarking Tool to complement their database for the next upgrade.

Table 2-7: Overview of hospital energy performance figures and targets in UK and EU (final energy)

Source	Country	Year of Data	Category	No of Data Points Monitored	Current Consumption kWh/m^2.yr			Target kWh/m^2.yr		
					Electricity	Heat	Total	Electricity	Heat	Total
Industry Guidance										
[91]	UK	Pre 1996	Acute Hospital	Unclear	108	510	618	74	422	**496**
[89]	UK	2006	General Acute Hospital	unclear likely abut 150	143	373	516	122	317	**439**
[92]	Germany	1999	hospital with up to 250 beds	102	53	289	342	32	170	**202**
			hospital with 251- 450 beds	76	87	243	330	45	172	**217**
			hospital with 451- 650 beds	46	77	314	391	48	204	**252**
			hospital with 651 - 1000 beds	27	78	308	386	308	36	**344**
			hospital with more than 1000 beds	31	164	446	610	446	47	**493**
Mandatory Disclosure										
[61]	UK (DEC)	?		unclear	90	420	510			
[61]	Germany (Energie-ausweis)	2007	hospital with up to 250 beds	111	120	205	325	84	145	**229**
			hospital with 251 - 1000 beds	104	115	250	365	80	175	**255**
			hospital with more than 1000 beds	33	115	285	400	80	200	**280**

Therefore, it is clear that for different purpose one needs to use the appropriate benchmark especially if it is for policy making. However, if the purpose is for energy efficiency auditing, one should consider that for such type of complex hospital building in this cluster, it is not appropriate to use these benchmarks at face value but some form of top-down or bottom up analysis needs to be carried out on individual blocks or interdepartmental energy used. Namely, one needs to consider both the top-down as well as the bottom-up approaches to arrive to the final EUI [88]. Both approaches are helpful depending on the scope to attain, but bottom-up methods calculate the energy consumption of individual end-uses, individual buildings, or groups of buildings, and then use these representative models to predict the regional or national energy consumption by different weighting approaches [93].Bottom-up methods can be further divided into two sub-categories based on their modelling mechanisms: statistical or engineering-based approach from first principles. Statistical energy use intensities on a system by system level can be found in the energy use benchmarked of CIBSE Guide F from which TM46 originated, as shown in Table 2-8 below.

Table 2-8: Breakdown of Hospitals energy used by services [94]

System	Delivered energy for stated hospital type* / (kW·h·m^{-2}) per year							
	Teaching		Acute		Cottage		Long stay	
	Good practice	Typical	Good practice	Typical	Good practice	Typical	Good practice	Typical
Fossil fuels:								
— space heating	215.3	249.4	296.3	308.2	322.1	345.1	251.8	332.4
— base load	123.4	161.6	126.1	202.1	121.2	146.7	148.9	186.0
Electricity:								
— lighting	20.0	40.0	20.0	40.0	11.8	23.5	11.0	22.0
— hvac	17.3	25.6	15.8	23.2	10.2	12.5	7.0	10.0
— other building services	11.9	13.4	11.8	13.1	10.1	13.1	9.9	13.1
— it equipment	6.0	6.7	5.9	6.5	1.2	1.6	1.2	1.6
— supplementary heating	2.8	3.1	2.7	3.0	4.7	6.0	4.5	6.1
— personal small power	11.0	14.0	11.0	14.0	11.0	14.0	11.0	14.0
— medical equipment	15.3	17.0	3.9	4.4	1.5	1.9	0.7	0.9
— catering	1.9	2.1	3.3	3.7	4.3	5.5	3.0	4.0
Total fossil	338.7	411.0	422.3	510.4	443.3	491.8	400.7	518.4
Total electricity	86.2	121.9	74.4	108.0	54.8	78.2	48.4	71.8

* based on a ceiling height of 2.9 m

In Ireland, Curtis and Pentecost [95] also examined the relationship between energy efficiency labels for residential buildings and household energy expenditure. They found that each rating along the scale is associated with a reduction in energy expenditure of 1.6%.

In Greece, Dascalaki et al. [96] analysed the 360,000 certificates issued since the certification system started in 2011 in terms of energy labels and calculated primary energy consumptions per unit floor area by building types, end-users, climate zones, and construction periods. They took data from Eurostat [97] , EU building stock observatory [98] and Odysee-Mure . The available information on the non-residential buildings in the reachable EU database stock is very limited, lacking specific data on building floor areas, construction characteristics and energy use breakdown for different services. The EUIs derived from the different European resources reveal significant deviations in some cases. The values for the various EUIs of the 28-member states were calculated as an average of the EU Building Stock Observatory and Odysee data. The available data of the final EUIs (kWh/m^2.yr) for different NR building types could only be generated for a limited number of countries for which the energy use and total floor area was [99] available, as shown in Table 2-9.

This table also included the average EUIs for each country non-residential buildings of the seven sectors harmonised for their normal climate heating DD. Dascalaki et al. found that, of the EU 28, there is a large variation of EUIs, averaging from 269.2kWh/ m^2.yr ±108.9 kWh/m^2 with a median at 245.7 kWh/m^2.yr. In fact, for some Member States, where this data was available, two readings were given ranging from the minimum to the maximum of energy use intensities.

Table 2-9: Final energy use intensities (kWh/m^2.yr) for non-residential building types in European countries (Data for 2013 from EU Building Stock Observatory Odyssey) [100]

Country	*Offices*	*Wholesale & Retail*	*Hotels & Restaurants*	*Health care*	*Education*	*All NR (normal climate)*
Austria						145.8 / -
Belgium						298.1 / -
Bulgaria		77.8 / -	96.5 / -	656.5 / -	219.3 / -	130.6 / -
Czech Repub-lic						201.4 / -
Croatia						239.9 / -
Cyprus						291.3 / -
Denmark						201.6 / 182.0
Estonia		479.6 / -	70.7 / -	147.8 / -	217.4 / -	403.1 / -
Finland						292.6 / 273.5
France	- / 280.9	255.8 / 256.7	391.0 / 393.3	228.2 / 232.4	143.6 / 154.5	276.1 / 240.1
Germany	130.8 / 154.5	151.3 / 148.3	212.3 / 201.5	317.2 / 328.5	108.5 / 98.2	238.6 / 187.0
Greece						300.1 / -
Hungary						203.7 / -
Ireland						186.4 / -
Italy						652.5 / -
Latvia						302.7 / -
Lithuania						136.9 / -
Luxembourg						350.4 / -
Malta	234.9 / -	394.2 / -	302.1 / -			436.6 / -
Netherlands	356.8 / -	174.1 / -	380.8 / -	237.8 / -	127.8 / -	149.0 / -
Poland						190.7 / -
Portugal						196.4 / -
Romania						345.0 / -
Slovakia						202.4 / -
Slovenia						387.5 / -
Spain		409.4 / -	46.1 / -	1124.3 / -	355.1 / -	318.8 / 316.9
Sweden	132.3 / 255.9	114.0 / 376.2	263.5 / 326.7	230.6 / 214.4	134.4 / 161.7	226.3 / 269.6
UK	278.8 / -	213.9 / -	314.3 / -	516.2 / -	237.6 / -	251.5 / -

In South Korea, the Building Energy Efficiency Certification System (BEECS) was enacted in 2001 and has been implemented as a policy tool to promote the reduction of building energy consumption by providing customers with information on building energy use [101].

Park et al. [102] discussed the South Korean building energy efficiency policies and the Building Energy Efficiency Certification System (BEECS). They examined the 933 large non-residential buildings, shown in Table 2-10 below, which consumed more than 2000 toe (>23.3MkWh) and discussed the influence these BEECS had on actual energy use.

Table 2-10: EUIs indicators for large buildings with more than 2000 toe per year (>23.3MkWh.) of energy use, annually, in South Korea

Parameter	Office	Retail	University/ Institute	Hotel	Hospital	Data Center	Apartment	Others
Number of buildings	164	174	148	61	80	55	221	30
Average building floor area (m^2)	110,205	92,399	195,216	114,221	91,735	28,812	227,463	106,618
Total final energy (ktoe)	344.7	319.6	471.5	203.9	267.1	146.1	545.9	70.8
Final energy use intensity(kWh/m^2)	221.7	231.2	189.8	340.2	423.3	1071.9	126.3	257.2

Although Europe has been leading the efforts in this area, mandatory or voluntary certification systems have also been introduced in many countries throughout the world [19], [103]. While the certification is mandatorily required for all buildings that are constructed, sold, or rented by a legislative instrument in the EU, the US involves private companies for certification, which seems to be a more market-driven approach.

2.6 Good practice Energy Use Intensities (EUIs) for non-residential buildings

Energy consumption is energy use plus wastage. By reducing wastage, consumption can be made more efficient without decreasing energy use. Becoming more efficient does not necessarily mean that one uses less energy. In policy making the meaning of saving is clear: Using less energy, i.e. the total energy consumption is reduced.

One way to measure energy consumption in non-residential buildings is by measuring EUIs. This measurement is calculated by collecting the energy used in a building for a whole year divided by its useful floor area. Energy use intensities (EUIs) are calculated in kWh/m^2 per year. EUIs are a rational way to compare energy use performance in buildings. On average energy use intensities for non-residential buildings in the EU are about 40% more energy intensive than residential buildings (250 kWh/m^2 compared to 180 kWh/m^2.yr).

EUIs can be specific for a particular service or more general for the whole building category, compared to standard yardsticks known as benchmarks, having an EUI that serves as a goal for designers or operators to attain the standards for good use. There are two principal ways on how to construct these benchmarks known as bottom-up or top-down approaches.

The top-down approach drives performance improvement by comparing the building to similar subsets of buildings to show whether it is a low or high performing building. It also identifies and prioritises cost-saving energy efficiency improvements and assesses the range of likely savings from these improvements. On the other hand, the bottom-up method for energy benchmarking aims to derive an index for energy performance based on the theoretical analysis of the building, taking into consideration the building's specific context. In fact, in the US these are sometimes known as energy use indexing.

Benchmark buildings are buildings which are smartly designed and constructed in the sense that they can act as categorised yardsticks for proper energy usage without infringing on the requirements of the users. Such buildings are generally:

- responsive to the requirements of occupants, organisations and society;
- sustainable in terms of energy and water consumption;
- low polluting in terms of carbon emissions and energy wastage;
- healthy in terms of wellbeing for the people living and working within them; and
- functional according to the users' needs.

It is to be noted that the benchmarks in this study make use of site energy use also known as: end-user or delivered energy. On the other hand, source energy or primary energy represents the total amount of raw fuel that is required to operate the building. It incorporates all generation, transmission, delivery, and production losses. By taking all energy use into account, the site benchmarks provide a complete assessment of energy efficiency in a building from the end users' point of view.

One process by which to construct a good practice benchmark for non-residential buildings, is explained in the CIBSE Guide F *Energy Efficiency in Buildings* [69], which practically came from TM22 energy assessment and reporting methodologies in buildings [104]. In the 2012 edition, a new section regarding the development of an energy strategy, was added. This reflects the changes to the UK government planning policy, which, at the time, included targets for reducing carbon dioxide emissions from new developments.

Besides the added section on energy-efficient refurbishment, which includes recognition of the pressing need to upgrade the existing building stock and the opportunities to improve performance, it also covered the operation of the building. This provides information on carbon reduction management, and the need for improved metering and monitoring. In its last sections it deals with benchmarking, monitoring and targeting, which aim at benchmarking energy efficiency in buildings, by analysing:

- energy invoice data (bills);
- hourly energy data of electricity and fuel used; and
- sub-meter readings.

This is carried out by relatively simple checks to improve the quality and accuracy of data acquired such as, to:

a) compare data with previous readings;
b) check if the number of digits is correct;
c) check if figures are within the accepted bands;
d) check the type of units used;
e) check reconciliation of meter readings and invoices; and
f) check if invoices are estimated or actual.

A range of analysis methods are then used for assessing building performance, and the four main methods are shown below.

Group tables: These are based on a range of factors, e.g. highest electricity intensity kWh/m^2.yr, highest emmission intensity CO_2/m^2.yr, etc. Group tables can be used to identify the best or worst performing buildings in a large scenario.

Benchmarks: A comparison is made with a standard consumption yardstick to establish how the building compares with typical and best practice buildings.

Performance lines: These lines make it possible to check whether the services continue to function concerning critical variables, such as changes in heating or cooling, consumption with degree-days during a certain period, occupancy, and work schedules.

Historical data: A comparison with a former measurement to ascertain whether previously adopted energy efficiency saving measures have been effective, and to identify the need for further improvement.

With these methods, actual energy consumption (EUIs) can:

- indicate when or where corrective action is needed;
- establish whether performance has been effective and should be replicated;
- evaluate the impact of changes in performance; and
- measure progress towards the target.

In this scenario, it can be helpful to carry out an analysis to determine the relationship between total monthly energy use and the constituents that influence it, such as fuel oil or electricity. As shown in Figure 2-17 a substantial part of this energy consumption is highly dependent on the outside weather which in turn is dependent on the location of the building on the planet. This energy consumption related to the different location scenario can be harmonised by using the degree-day methodology. Since the DD method gives an indication of the yield of a climate and linearly calculates its expected consumption during the winter or summer season. The area under the red or blue lines gives the seasonal energy consumption. When the building is cooled by natural ventilation during the mid-season period, the energy use is not considered so the graph line in Figure 2-17 is dashed.

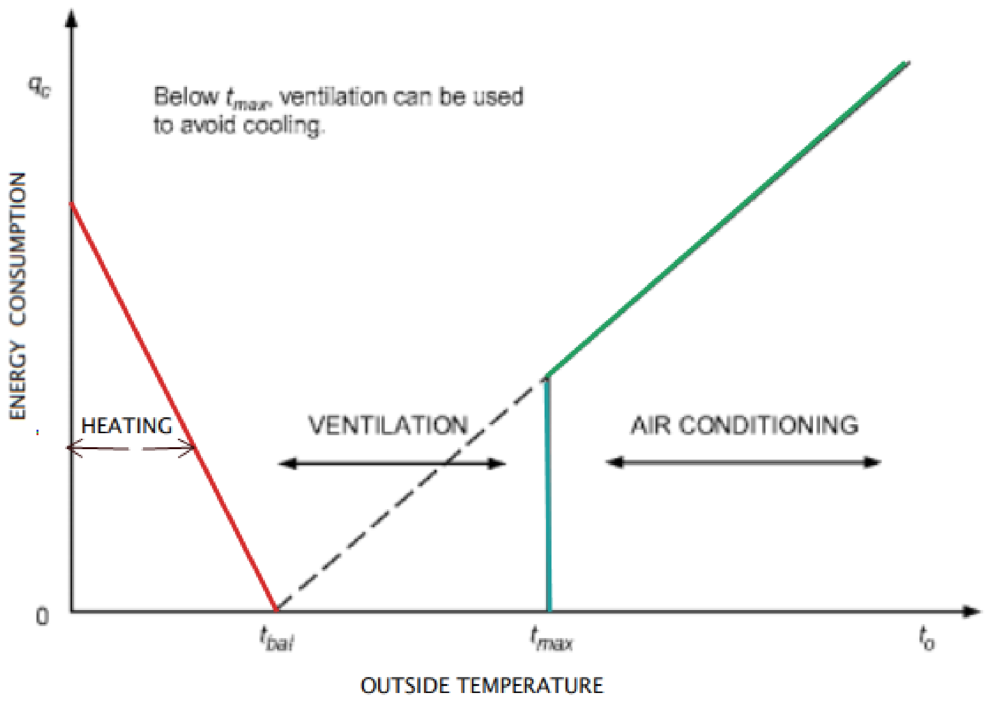


Figure 2-17: Heating and cooling load as a function of outdoor temperature [105]

In reality, when the monthly Degree Days are superimposed on the monthly energy consumption they show that such trends follow the same paths as shown in Figure 2-18 [69], which shows the monthly fuel consumption and the related heating Degree Days . Similarly, during the cooling scenarios, the monthly electricity consumption should relate to cooling Degree Days when the chiller plants are in operation.

Since in practice degree-days are the summation of outside temperature differences from a selected base over time, they capture both extremity and duration of outdoor temperatures. The temperature difference is between a reference temperature (base temperature) and the hourly outdoor air temperature.

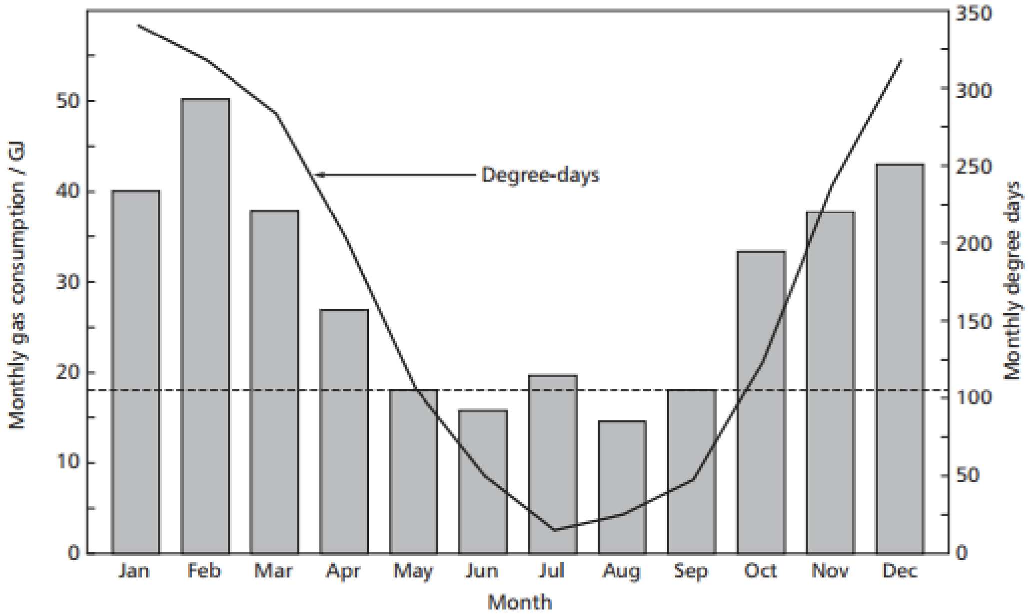


Figure 2-18: Relationship between energy use and degree days in UK [69]

If the energy consumption, *E* is plotted against the degree days, *DD* over a period of time, it aproximately represents a linear function of the form

$$\mathbf{E} = \mathbf{mDD} + \mathbf{c} \qquad \mathbf{Wh} \tag{2-1}$$

where the intercept c is the base load, i.e. the energy that is not weather-dependent, while the gradient *m* represents the weather-related energy use.

To demonstrate the outcome of a real-life situation during a heating season of a typical project that uses fuel oil and electricity for its process, a practical example is shown in Figure 2-19. The intercept i.e. where DD are 0, shows the consumption of the building when no space heating is required (i.e. the baseload). The value on the graph at this point is 600,000 kWh ,which could represent the energy used for the production of say hot water, lighting, IT, power connected loads, etc. While the variable contribution (m DD) is the 'weather-dependent' part of the energy use, that is, the contribution of space heating.

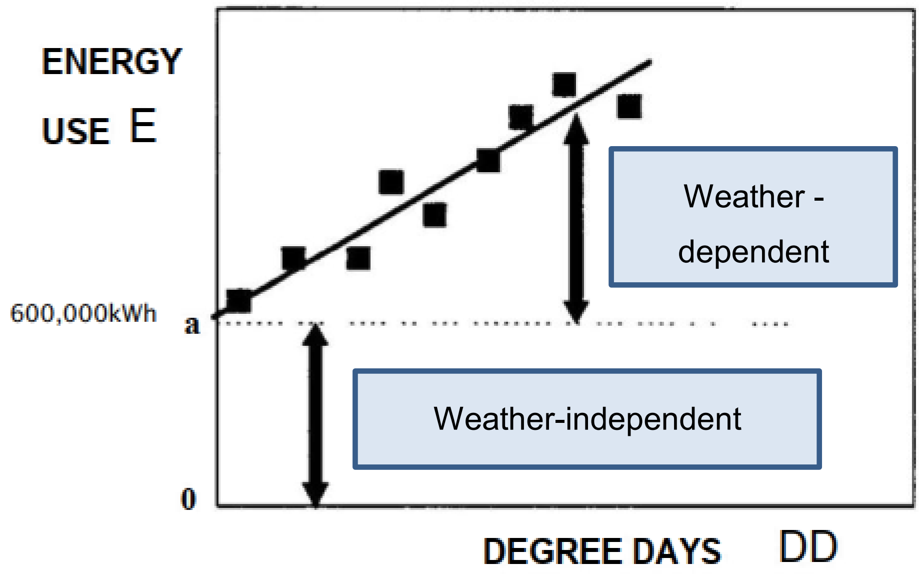


Figure 2-19: Energy consumption in a building versus degree-days showing base load.

With this in mind EUIs for a whole year against the useful areas can be constructed, since all buildings, if properly designed and managed, should consume the same amount of energy. This subject to design intent, type of building, internal conditions, occupancy, operation schedules and the added component that is related to external ambient conditions.

Having applied all the criteria given above the last part of this Guide F [69] gives the energy use intensities for various good practice benchmarks in terms of energy used per m^2 per year in non-residential buildings as a whole or for each service, according to the class of design, as partly shown in Figure 2-20. Values given in shaded columns may be regarded as optimum targets for new designs. These tables also show the typical EUI values, which were taken from actual samples of over 50 large non-residential buildings. The size of the sample is very important for the reliability of the benchmark and one has to be careful when comparing a particular building with the benchmarks based on smaller samples.

Building type	Energy consumption benchmarks for existing buildings / (kW·h·m^{-2}) per year (unless stated otherwise)				Basis of benchmark
	Good practice		Typical practice		
	Fossil fuels	Electricity	Fossil fuels	Electricity	
Entertainment: (continued)					
— social clubs	140	60	250	110	Gross floor area[b]
— bingo clubs	440	190	540	230	Gross floor area[b]
Education (further and higher)[3][c]:					
— catering, bar/restaurant	182	137	257	149	Gross floor area
— catering, fast food	438	200	618	218	Gross floor area
— lecture room, arts	100	67	120	76	Gross floor area
— lecture room, science	110	113	132	129	Gross floor area
— library, air conditioned	173	292	245	404	Gross floor area
— library, naturally ventilated	115	46	161	64	Gross floor area
— residential, halls of residence	240	85	290	100	Gross floor area
— residential, self catering/flats	200	45	240	54	Gross floor area
— science laboratory	110	155	132	175	Gross floor area
Education (schools)[4]:					
— primary	113	22	164	32	Gross floor area
— secondary	108	25	144	33	Gross floor area
— secondary (with swimming pool)	142	29	187	36	Gross floor area

Figure 2-20: Typical fossil and electric building benchmark in EUIs

Such benchmarks are also helpful during energy monitoring and auditing, where one can compare actual consumption with typical or good practice usage. Further auditing can be done by focusing on end-uses to identify where, why and when inefficiencies are occurring.

Such benchmarks can also be used as strategy objectives when identifying targets for key performance indicators (KPIs) to be focused on for support in Energy Management Systems (EnMS), such as that recommended in ISO 50001 [106]. ISO 50001 is the globally recognised energy management standard developed by the International Organisation for Standardization. It serves as a framework for effectively managing the energy that an organisation uses in its premises. It works on the principle that energy consumed is equal to the summation of energy use plus waste. Now, instead of the intricacy to reduce energy use, one considers reducing waste by having more efficient buildings, thus the energy consumption is reduced automatically. The standard also helps non-residential buildings understand where the energy is used and how it can be managed effectively with control on consumption and costs in the future.

2.7 Global benchmarks comparison

As its name implies, benchmarking is the practice of comparing the measured performance of a building, process, facility, or organisation to itself, its peers, or established norms, with the goal of informing and motivating performance improvement.

As stated by the U.S. Department of Energy (DOE) [107] this practice, when used for benchmarking serves as an instrument to measure energy performance of a building over time, relative to other buildings, or to theoretical analysis simulations of a reference building built to specific standards.

Complementary to this, energy management systems are all about following the evolution of energy use and identifying opportunity schemes for improvement. This relates to past performance and to how current performance compares with other buildings, especially those of a similar type.

Besides UK and Malta, this thesis examines what type of benchmarks are used in other counties in Europe such as Germany, France, the Netherlands and Sweden, as well as the US and South Korea. As explained above, the energy use in non-residential buildings is practically similar in all locations except for its weather-dependent component which hinge on the building's geographic and regional location. To compensate for this variation, the number of annual degree days can give an indication of its yield or severity, as in Table 2-11.

Table 2-11: Details of countries whose benchmarks (EUIs) for non-residential buildings were examined

Country	**Europe**						**North America**	**Asia**
	UK	Malta	Germany	France	Netherland	Sweden	US[5]	S. Korea
City	London	Valletta	Berlin	Paris	Amsterdam	Stockholm	Various	Seoul
Latitude	51 N	35.7N	52.5N	48.2N	52.3N	59.4N	Various	37.5N
Total Degree Days[1]	2021	1412	2508	2548	2093	3320	Various	3130
Rating Operational/Asset)[2]	OR[3]	AR[4]	AR[4]	AR[4]	AR[4]	AR[4]	OR[3]	OR[3]
Practice	Good	Normal	Normal	Normal	Normal	Normal	50th percentiles surveyed	Normal

1- Degree days taken from Bizee software

2- Operational Rating from actual consumption bills. Asset Rating from EPCs

3- Good practice benchmarks or normal from typical installed non-residential buildings

4- Taken from EU Building Stock Observatory database

5 -2012 survey done by the Commercial Buildings Energy Consumption Survey (CBECS)

One has to note that the above DD for each location were calculated for standard heating and cooling base temperature of 15.5°C and 18.5°C, respectively, using BizEE software [108] which has temperature data from thousands of weather stations worldwide.

Recently, CIBSE together with the Energy Institute of University College London (UCL) issued a test version of a new digital energy benchmarking tool based on CIBSE TM46, built on a report analysing more than 120 thousand display energy certificates [109]. The online platform uses energy data as inputted by designers or operators, which becomes available to provide relevant and reliable benchmarks that represent the current trends of energy use in buildings.

Based on TM46 (which originated from Table 20.1 of the CIBSE Guide F) and the available historic DECs data, this tool features:

- a new method for the production of energy use intensity benchmarks;
- a dynamic way to present energy benchmarks in a graphical format (based on the cumulative frequency distribution) with interactive features as illustrated in the example in Figure 2-21, for a special school with 177 kWh/m^2.yr of electricity consumption, as well as making use of a tabular format;
- regional (geographic and climate regions of UK) as well as national energy benchmarks;
- the capacity for regular updates without having to wait for the longer revision cycle of printed publications.

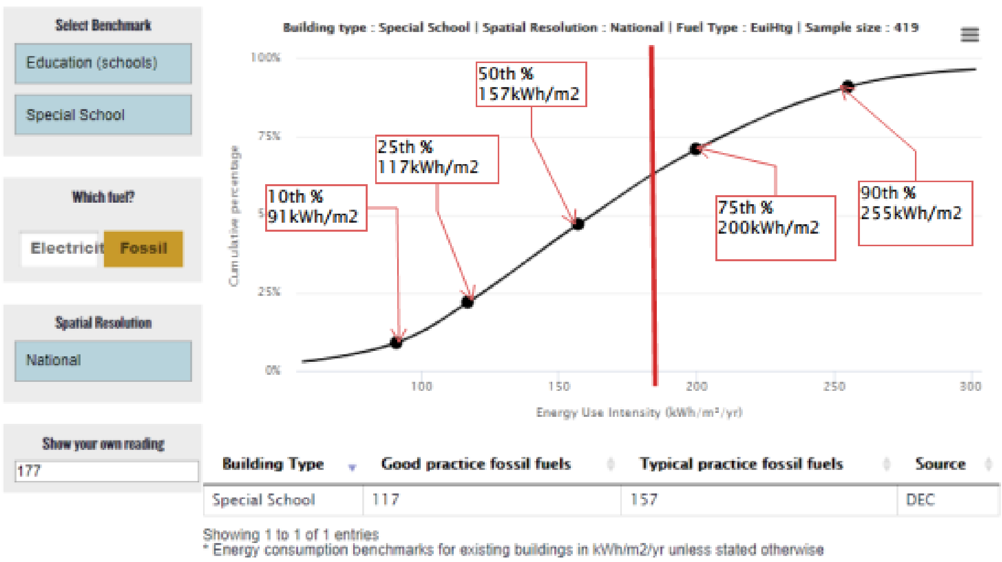


Figure 2-21: Typical example using the CIBSE digital benchmarking tool in comparison to good practice, typical practice and percentiles

A paper presented by Dascalaki et.al. [96] on energy use intensities [100] gave a list of typical energy use benchmarks for all the EU member states complied from the Building Stock Observatory [98] Odyssee-Mure [110] databases, as previously shown in Table 2-9..

The EU Building Stock Observatory is under the jurisdiction of the Directorate General for Energy. It provides a broad snapshot of the building stock characteristics in the 28 EU Member States, and includes data from EU projects, national statistics, EPC databases, cities' sustainable energy action plans, industry data, and other sources with fact sheets on specific topics for each individual country.

While the Odyssee-Mure databases are coordinated by the French Environment and Energy Management Agency (ADEME) and co-funded by the Horizon 2020 programme of the European Commission, a network of 37 partners from 31 countries, usually national energy efficiency agencies are involved.

These values were taken from actual EPCs and included the annual energy consumption for end users in $kWh/m^2.yr$ split into five different categories in non-residential buildings namely Offices, Warehouses & Retail Outlets, Hotels and Restaurants, Health Care and Education.

The final EUI ($kWh/m^2.yr$) for different non-residential building types could only be generated from EPCs based on asset rating of their different methodologies for a limited number of countries, for which the energy use and total floor area was available. This included for space heating, water heating and lighting as shown in Table 2-9 above.

As per EPBD requirements, these benchmarks do not include energy use consumption for equipment, IT, plumbing, connected plug loads etc. Furthermore, only seven non-domestic building categories are included. These are: Offices; educational buildings; hospitals; hotels and restaurants; buildings used for wholesale and retail trade services; and other types of energy consuming buildings. Balaras et.al. [100] highlighted that a lot of data from Member States was missing and it was hard to identify the exact category of the buildings referred to, since Healthcare building could be either a hospital or a simple clinic with quite different energy usage.

On the other hand, in the U.S. there are two sources for benchmarked non-residential buildings. One is a free web-based portal through Energy Star programme [111] using the Portfolio Manager [112] as a software .The Portfolio Manager normalizes the Energy Use Intensities i.e. uses it as a building benchmark type for various climates within the US, which facilitates pre-determined benchmarks as yardsticks for setting goals in the energy use of new or renovated buildings. It also helps compare multiple buildings all over the world in a portfolio and is useful for numerous building types. It is an operational type of rating (OR) as shown in Table 2-12 and is fully online. The Portfolio Manager can be used to measure and track energy and water consumption, as well as greenhouse gas emissions.

Table 2-12: Average EUIs in the United States for
Energy Star programme [112]

Market Sector	**Property type**	**End User**	**Primary Energy**
		kWh/m² per yr	**kWh/m² per yr**
Banking/Financial services	Bank branch	279	662
Banking/Financial services	Financial office	167	367
Education	College/University	266	570
Education	K-12 school	153	329
Education	Pre-school/Day-care	204	415
Education	Vocational school/Adult education	165	348
Public assembly	Convention centre/Meeting hall	177	346
Public assembly	Recreation/Athletic centres	160	353
Public assembly	Entertainment	177	353
Public assembly	Worship facility	96	184
Food sales & service	Convenience store	730	1869
Food sales & service	Bar/Nightclub	412	937
Food sales & service	Fast food restaurant	1270	2796
Food sales & service	Restaurant	1027	1810
Food sales & service	Supermarket/Grocery store	618	1401
Food sales & service	Wholesale club/Supercentre	162	379
Healthcare	Ambulatory surgical centre	196	436
Healthcare	Hospital (General medical & surgical)	739	1347

Market Sector	Property type	End User	Primary Energy
		kWh/m² per yr	kWh/m² per yr
Healthcare	Other/Specialty hospital	652	1369
Healthcare	Medical office	162	384
Healthcare	Outpatient rehabilitation/Physical therapy	196	436
Healthcare	Urgent care/Clinic/Other outpatient	203	460
Lodging/Residential	Barracks	183	339
Lodging/Residential	Hotel	199	463
Lodging/Residential	Multifamily Housing	188	373
Lodging/Residential	Prison/Incarceration	220	493
Lodging/Residential	Residence hall/Dormitory	183	339
Lodging/Residential	Residential care facility	312	673
Mixed Use	Mixed use property	126	282
Office	Medical office	162	384
Office	Office	167	367
Office	Veterinary office	203	460
Public Services	Courthouse	319	667
Public Services	Fire/Police station	200	394
Public Services	Library	226	453
Public Services	Mailing centre/Post office	151	306
Public Services	Transportation terminal/Station	177	353
Retail	Automobile dealership	173	391
Retail	Enclosed mall	207	538
Retail	Strip mall	326	722
Retail	Retail store	326	379
Technology/Science	Laboratory	364	1004
Services	Dry cleaning, Shoe repair, Locksmith, Salon, etc.	151	306

Market Sector	Property type	End User	Primary Energy
		kWh/m² per yr	kWh/m² per yr
Utility	Drinking water treatment & distribution	7	19
Utility	Energy/Powers station	126	282
Warehouse/Storage	Self-storage facility	64	151
Warehouse/Storage	Distribution centre	72	167
Warehouse/Storage	Non-refrigerated warehouse	72	167
Warehouse/Storage	Refrigerated warehouse	265	743

Another US resource is the 2012 survey carried out by the Commercial Buildings Energy Consumption Survey (CBECS) for the Energy Information Administration [113] [114]. This survey gives statistical information on energy-related characteristics, consumption, and expenditures for the US commercial building sector. The data is organised by building size, age, principal building activity, region, climate zone and other building attributes.

Figure 2-22 represents building benchmarks developed from a methodology similar to that used in the development of building energy performance targets for ASHRAE Standard 100 [77]. The ASHRAE standard essentially offers over 100 typical energy efficiency measures (EEMs) that can be applied to enable buildings to meet set energy targets, identifying commonly applied elements that can improve building energy performance.

Building Use	Calculated, Weighted: Number of Buildings, Hundreds	Calculated, Weighted: Floor Area, 10^9 m²	Actual Number of Buildings, N	EUI Percentiles: 10th	25th	50th	75th	90th	Mean
				Calculated, Weighted Energy Use Index (EUI) Values Site Energy, MJ/yr per gross square metre					
Administrative/professional office	442	0.62	555	286	420	630	947	1407	761
Bank/other financial	104	0.10	75	568	688	887	1196	1873	1084
Clinic/other outpatient health	66	0.07	100	293	414	678	990	1787	860
College/university	34	0.13	88	144	684	1098	1815	2189	1246
Convenience store	57	0.01	28	699	1590	2362	3591	4233	2792
Convenience store with gas station	72	0.03	32	838	1375	2149	2836	4177	2300
Distribution/shipping center	155	0.49	231	89	169	333	550	927	463
Dormitory/fraternity/sorority	16	0.05	37	370	663	754	1022	1566	919
Elementary/middle school	177	0.44	331	215	355	553	944	1293	770
Entertainment/culture	27	0.05	50	17	300	470	1369	4264	972
Fast food	78	0.02	95	1799	2737	4262	8327	9514	5451
Fire station/police station	53	0.04	47	70	249	841	1146	1402	795
Government office	84	0.14	150	321	532	780	1055	1525	869
Grocery store/food market	86	0.07	117	1000	1407	1892	2441	4457	2174
High school	68	0.23	126	202	444	662	1008	1330	765
Hospital/inpatient health	8	0.18	217	1103	1728	1998	2844	3619	2319
Hotel	20	0.18	86	405	522	745	1182	1872	968
Laboratory	9	0.06	43	999	1681	2759	5152	9433	3691
Library	20	0.05	36	357	682	935	1232	2008	1064
Medical office (diagnostic)	54	0.05	58	143	251	453	1018	1402	609
Medical office (nondiagnostic)	37	0.02	33	262	407	532	678	1108	598
Mixed-use office	84	0.21	172	204	390	724	1077	1614	896
Motel or inn	70	0.10	109	243	373	688	1041	2013	885
Nonrefrigerated warehouse	229	0.28	172	23	63	194	466	888	347
Nursing home/assisted living	22	0.09	73	424	781	1179	1876	2095	1268
Other	70	0.10	68	56	295	708	975	1199	759
Other classroom education	51	0.07	60	44	232	404	658	1098	519
Other food sales	10	0.01	10	321	375	596	1938	3504	1286
Other food service	58	0.03	56	404	724	1274	3154	5590	2470
Other lodging	16	0.06	28	318	546	722	843	1492	776
Other office	73	0.04	52	156	416	578	854	1494	708
Other public assembly	32	0.04	31	101	307	431	749	1583	660
Other public order and safety	17	0.07	38	449	592	951	1636	3143	1297
Other retail	47	0.02	42	334	659	936	1486	2092	1222
Other service	139	0.04	171	285	506	881	1671	3095	1712
Post office/postal center	19	0.05	23	73	588	651	771	990	648
Preschool/daycare	56	0.04	46	191	360	597	1138	1234	765
Recreation	96	0.12	99	137	245	403	897	1550	689
Refrigerated warehouse	15	0.05	20	66	134	1455	1939	2622	1300
Religious worship	370	0.35	313	95	178	334	648	901	468
Repair shop	76	0.06	51	71	128	304	550	730	379
Restaurant/cafeteria	161	0.10	212	529	1192	2107	4711	6483	3077
Retail store	347	0.32	460	145	257	461	945	1734	737
Self-storage	198	0.12	84	22	43	72	98	155	88
Social/meeting	101	0.11	78	80	149	420	721	949	532
Vacant	182	0.24	178	14	31	117	313	781	270
Vehicle dealership/showroom	50	0.06	40	250	408	839	1118	2528	1127
Vehicle service/repair shop	212	0.11	131	103	162	381	879	1393	592
Vehicle storage/maintenance	176	0.11	99	9	44	214	545	1548	553
SUM or Mean for sector	4645	6.02	5451	100	267	572	1105	2116	991

Source: Calculated based on DOE/EIA preliminary 2012 CBECS microdata.

Figure 2-22: Energy use benchmarks for typical non-residential buildings in the U.S. [115]

Table 2-14 was compiled using this research, to give the EUIs for a select group of European states, the US and South Korea. This gives a better overview of the diversity of the EUIs values for same category buildings, when compared to other countries. The building categories selected for the EU Member States EUIs are corelated to those of corresponding similar building types schedule, as listed in the UK TM46 benchmarks, shown in Table 2-13..

Table 2-13: Allocation of European building types to Categories as given in TM46

Building Type	item	Allocated category as per TM46
Office	21	1
Retail & warehouse	59	4
Hotel	55	9
Healthcare	157	19
Educational	138	17

From Table 2-14 it can be noted that the few energy benchmarks of the selected EU member states, vary considerably. For example, the EUI for Category One for general office buildings, varies from 154kWh/m^2 in Germany to 356kWh/m^2 in the Netherlands. On considering that these two countries are practically on the same global latitude with not so much difference in their total degree-days, one would have expected much lower discrepancy. This phenomenon is also noted for the other categories. The causes, though puzzling, require a separate study, which is outside the main scope of this thesis. However, the fact remains that there is a lack of harmonisation of EUIs between EU Member States; an aspect which was acknowledged by the (EU) 2018/844 EPBD which intends to address just this matter, within 10 years from 2020. As mentioned before, the intention is to have a trending shift towards operational rating EUIs.

As for the US, as presented in Table 2-14, the EUIs, were taken from the Portfolio Manager of the Energy Star programme[112] from data displayed in. The listed EUIs differ significantly from the benchmarks of the UK and other countries. This difference is sometimes negative and sometimes positive depending on the category. An explanation for this finding could be that the US is a large country spanning over ten latitude degrees, and therefore it is hard to represent categories with single EUIs for the whole country.

On the other hand, South Korea's latitude, very near to that of Malta, has a very high total DD of 3130, calculated using BizEE software [108]. The EUIs, as compiled by Park et.al. [102] for the seven category buildings from actual billing studies, were compared to the UK energy benchmarks and found to be satisfactory.

Table 2-14: Energy Use Intensities (EUIs) for various countries for different categorised buildings

Cat	Building Type	Brief description	Non-residential Buildings Benchmarks (EUI) (kWh/m^2)							
			UK[1]	Malta[2]	Germany[3]	France[3]	Netherlands [3]	Sweden[3]	US[4]	S Korea [5]
1	**General office**	General office and commercial working areas	**215**	**135**	**154**	**281**	**356**	**255**	**157**	**345**
2	**High street agency**	High street agency	**140**						**167**	
3	**General retail**	General street retail and services	**165**						**173**	
4	**Large non-food shop**	Retail warehouse or another large non-food store	**240**	**224**	**151**	**257**	**174**	**376**	**326**	**237**
5	**Small food store**	Small food store	**310**						**162**	
6	**Large food store**	Supermarket or other large food store	**505**						**618**	
7	**Restaurant**	Restaurant	**460**	**445**					**1027**	
8	**Bar, pub or licensed club**	Bar, pub or club	**480**						**412**	
9	**Hotel**	Hotel or boarding house	**435**	**228**	**213**	**393**	**380**	**326**	**199**	**340**
10	**Cultural activities**	Museum, art gallery or other public building with normal occupancy	**270**						**160**	
11	**Entertainment halls**	Entertainment halls	**570**						**177**	

Cat	Building Type	Brief description	Non-residential Buildings Benchmarks (EUI) (kWh/m²)							
			UK[1]	Malta[2]	Germany[3]	France[3]	Netherlands [3]	Sweden[3]	US[4]	S Korea [5]
12	**Swimming pool centre**	Swimming pool hall, changing and ancillaries	**1375**							
13	**Fitness and health centre**	Fitness centre	**600**							
14	**Dry sports and leisure facility**	Dry sports and leisure facility	**425**	**179**						
15	**Covered car park**	Car park with roof and side walls	**20**							
16	**Public buildings with light usage**	Light use public and institutional buildings	**125**						**200**	
17	**Schools and seasonal public buildings**	Public buildings nominally used for part of the year	**190**	**107**	**109**	**154**	**127**	**269**	**153**	**190**
18	**University campus**	University campus	**320**						**260**	
19	**Clinic**	Health centres, clinics and surgeries	**270**		**328**	**232**	**237**	**234**	**196**	
20	**Hospital; clinical and research**	Clinical and research hospital	**510**						**739**	**421**
21	**Long term residential**	Long term residential accommodation	**485**						**652**	
22	**General accommodation**	General accommodation	**360**	**214**					**188**	
23	**Emergency services**	Emergency services	**460**						**203**	

Cat	Building Type	Brief description	Non-residential Buildings Benchmarks (EUI) (kWh/m²)							
			UK[1]	Malta[2]	Germany[3]	France[3]	Netherlands [3]	Sweden[3]	US[4]	S Korea [5]
24	**Laboratory or operating theatre**	Laboratory or operating theatre	**320**						**652**	
25	**Public waiting or circulation**	Bus or train station, shopping centre mall	**150**						**226**	
26	**Terminal**	Regional transport terminal with concourse	**275**						**177**	
27	**Workshop**	Workshop or open working area (not office)	**215**						**173**	
28	**Storage facility**	Storage warehouse or depot	**195**						**72**	
29	**Cold storage**	Refrigerated warehouse	**225**						**265**	

Notes

1 Taken from UK TM46 (CIBSE) for Good Practice non-residential buildings

2 Cost Optimal EUIs for Malta as given in Table 2-5

3 Energy Use Intensities taken from EPC (AR) EU Building Stock Observatory database

4 Taken from Energy Star Portfolio Manager for Average EUIs. Conversion taken at $kBTU/ft^2 = 3.154 kWh/m^2$

5 Analysis of a Building Energy Efficiency Certification S Korea by Duk Joon Park et.al. [102]

2.8 UK weather-dependent and weather-independent energy benchmarks for buildings

In CIBSE TM46 *Energy Benchmarks* [61] the benchmarks have an additional feature, which gives that part of the energy use intensity related to the outside weather. In fact, they are used to give the non-residential building the statutory energy consumption rating for the Operational Rating (OR) procedure to produce the DECs.

The data contained in this Technical Manual is based on the original CIBSE Guide F and its various Energy Consumption Guides (ECG) data, updated to take account of more recent additions to the original data sets, especially in line with recent legislation to reduce the carbon footprint of buildings.

In Chapter Five of this thesis, this data is analysed and appropriately adapted for local needs. Moreover, this benchmark manual lists 237 other types of buildings, where each building type can be allocated to any of the 29 categorised benchmarks, as partly shown in Figure 2-23 below.

No.	Building type	Benchmark category	Category name
1	Adult education centre	1	General office
2	Air traffic control	1	General office
3	Bank office	1	General office
4	Building society office	1	General office
5	Business units	1	General office
6	Call centre	1	General office
7	Central government office	1	General office
8	Commercial office	1	General office
9	Conference centre	1	General office
10	Courts	1	General office
11	Crown and county courts	1	General office
12	Crown court	1	General office
13	Financial service office	1	General office
14	Flight crew facility	1	General office
15	Guardroom	1	General office
16	Law facilities	1	General office
17	Legal/financial services	1	General office
18	Local government office	1	General office
19	Office showroom	1	General office

No.	Building type	Benchmark category	Category name
64	Warehouse shop	4	Large non-food shop
65	Warehouse showroom	4	Large non-food shop
66	Corner food shops, butchers	5	Small food store
67	Corner food shops, greengrocers and delicatessens	5	Small food store
68	Supermarket	6	Large food store
69	Cafe	7	Restaurant
70	Canteen	7	Restaurant
71	Eating place	7	Restaurant
72	Food courts	7	Restaurant
73	Mess, junior ranks (accommodation only)	7	Restaurant
74	Mess, junior ranks (catering only)	7	Restaurant
75	Mess, officers (catering only)	7	Restaurant
76	Mess, warrant officers and sergeants (catering only)	7	Restaurant
77	Motorway service areas	7	Restaurant

Figure 2-23: Allocation of building types for different benchmark categories

As a general presentation Table 2-15, sourced from this manual, categorises the 29 types of buildings and gives a brief description of their characteristics and operations, the reference operating hours per year and distinguished features such that:

- Columns A, B and C give a brief description of the building;
- Columns D,E,F and G indicate space usage;
- Columns H, I, J and K provide an indication of the services included, if uses are mixed, particular energy usage and if representative of buildings.

This table will be used as the input database for the proposed methodology and eventually for processing the suggested benchmarks for non-residential buildings for Malta.

Table 2-15: UK weather-dependent/ unrelated benchmark categories and values with allocation guides and further category details

A	B	C	D	E	F	G	H	I	J	K
Name and description			Allocation guides				Further category details			
Cat	**Name**	**Brief description**	**Space usage**	**Operational schedule**	**Reference hours per year**	**Distinguishing features**	**Services included**	**Maybe part of mixed-use with areas below**	**Summary of allowable unique energy uses**	**Representative buildings**
1	**General office**	General office and commercial working areas	Mainly by employees, for sedentary desk-based activities. Includes meeting and conference facilities.	Weekdays and early evenings	2040	The relative uniformity of occupancy, density, conditions, schedule and appliances	Heating, lighting, cooling, employee appliances, standard IT, basic tearoom	Covered car park, staff restaurant	Regional server room, trading floor	General office benchmark category for all offices whether air-conditioned or not, Town Halls, architects, various business services that do not include retail functions
2	**High street agency**	High street agency	By employees mainly for desk-based activities and off-street visitors — public area and back office	Weekdays and early evenings, commonly part or all of the weekend	2660	Office type of activities, with retail street frontage, and consequent infiltration and glazing losses	Heating, lighting, cooling, employee appliances, standard IT, basic tearoom			Bank branches, estate agents, travel agents, legal, insurance and advertising services, off-street professional services, post offices, betting shops
3	**General retail**	General street retail and services	Mainly by clients, customers and visitors for a service activity — some facilities required for employees	Weekdays and early evenings, commonly part or all of the weekend	2660	Basic heating, lighting, cooling for off-street premises that may contain a wide variety of activities besides the sale of goods	Heating, lighting, cooling, appliances for small number of employees			High street store or local stores. Corner shops, amusement arcades, takeaways, hairdressers, laundries, laundrettes, dry cleaners, hire premises, indoor markets
4	**Large non-food shop**	Retail warehouse or another large non-food store	Mainly by customers for purchasing goods — some facilities required for employees	Typically, week and weekend days	2660	Large, and tends to be solely used for retailing	Heating, lighting, cooling, appliances for small number of employees			Retail warehouses or shed, department stores, hypermarkets, large showrooms

A	B	C	D	E	F	G	H	I	J	K
	Name and description		Allocation guides				Further category details			
Cat	Name	Brief description	Space usage	Operational schedule	Reference hours per year	Distinguishing features	Services included	Maybe part of mixed-use with areas below	Summary of allowable unique energy uses	Representative buildings
5	**Small food store**	Small food store	Mainly by customers for purchasing goods — some facilities required for employees	Typically, week and weekend days	2660	Greater needs for refrigeration of goods than other shops	Heating, lighting, display cabinets, food storage, employee appliances			Food stores, greengrocers, fish shops, butchers, delicatessens
6	**Large food store**	Supermarket or other large food store	Mainly by customers for purchasing goods — some facilities required for employees	Typically, week and weekend days; may be used in evenings; some are 24/7 operations	2860	Greater needs for refrigeration of goods, and larger, than other shops	Heating, lighting, display cabinets, food storage, employee appliances	Covered car park	Bakery oven	Supermarkets and freezer centres
7	**Restaurant**	Restaurant	Storage and preparation of food which is then cooked and served to users; seating space for eating is provided	There is a wide variety of operational schedules, from selected portions of weekdays to 24/7 operation	3060	Assumes minimal reheat of food.	Heating, lighting, cooling, food storage, heating of pre-prepared food		Cooking equipment in a catering kitchen	Cafes, restaurants, canteens, refectories, mess halls
8	**Bar, pub or licensed club**	Bar, pub or club	Serving drinks and snacks, with standing and sitting areas for customers	Open to public or members, day and evening	3060	Major activity is the bar and associated areas	Heating, lighting, cooling, some office appliances, snack provision			Pubs licensed clubs, members clubs, wine bars

A	B	C	D	E	F	G	H	I	J	K
	Name and description		Allocation guides				Further category details			
Cat	Name	Brief description	Space usage	Operational schedule	Reference hours per year	Distinguishing features	Services included	Maybe part of mixed-use with areas below	Summary of allowable unique energy uses	Representative buildings
9	**Hotel**	Hotel or boarding house	Primarily the provision of short-term accommodation and hygiene facilities	Primarily used in evenings	6560	Provision for paid short term accommodation	Heating, lighting, cooling, some office appliances, laundry services	Swimming pool, fitness and health centre, restaurant, general office (for conference facility)		All hotel types, guest houses, motels
10	**Cultural activities**	Museum, art gallery or other public building with normal occupancy	Spaces for displaying and viewing objects, with associated office and storage facilities	Daytime use, similar to office hours but more likely to be open in weekends	2040	Activity is office like in its requirements but with some additional conditioning requirements for display and storage of artefacts	Heating, lighting, cooling, humidity control			Municipal museums, libraries and galleries, higher education arts buildings
11	**Entertainment halls**	Entertainment halls	Large assembly and seating areas, with associated ticketing and snack services, for performance events and films	Mainly in evenings, some daytime use. All days of week	2548	Tend to be large halls, mainly used in evenings	Heating, lighting, cooling of main entertainment spaces, and circulation. Ticketing and snacks provision			Cinemas, theatres, concert halls. Bingo halls
12	**Swimming pool centre**	Swimming pool hall, changing and ancillaries	Swimming pool with associated facilities	Ranges from occasional use to daily and evening	2856	Pool hall is the dominant space use — may have small café and fitness room	Heating, lighting, cooling of all spaces. Office appliances, showers, snack provision and bar			Swimming pool centre without further sports facilities

A	B	C	D	E	F	G	H	I	J	K
	Name and description		Allocation guides				Further category details			
Cat	Name	Brief description	Space usage	Operational schedule	Reference hours per year	Distinguishing features	Services included	Maybe part of mixed-use with areas below	Summary of allowable unique energy uses	Representative buildings
13	**Fitness and health centre**	Fitness centre	Fitness, aerobics, dance and solarium/sauna facilities	Typically, daily and evenings	2754	Provision of sports and entertainment equipment with generally high energy usage, and internal gains	Heating, lighting, cooling of all spaces. Office appliances, showers, snack provision and bar			Fitness centre, health centre
14	**Dry sports and leisure facility**	Dry sports and leisure facility	Dry sports and club house buildings — for a combined leisure centre include pool etc.	Ranges from occasional use to daily and evening	2754	Provision of space to support separated sporting and entertainment activities often lightly serviced	Heating, lighting and basic office equipment	Swimming pool, fitness and health centre	Sports flood lighting	Dry sports halls, sports grounds with changing rooms, tennis courts with office, speedway tracks, stadiums, pavilions
15	**Covered car park**	Car park with roof and side walls	Provision for car parking and access	Weekday or 24-hour	4284	Lighting and mechanical ventilation when in use.	Lighting and ventilation	Office, public building in central urban location	Lighting and ventilation	Office, public building in central urban location
16	**Public buildings with light usage**	Light use public and institutional buildings	Variety of facilities and services provided with generally public access when in use	Intermittent usage	2040	Lightly serviced or lightly used	Heating and lighting			
17	**Schools and seasonal public buildings**	Public buildings nominally used for part of the year	Teaching and community activities	Weekday usage for part of the year	1400	Public buildings with part annual occupancy	Heating, lighting and basic office equipment, teaching equipment, computers	Restaurant (dining hall), swimming pool		Primary and secondary schools, nurseries, creches, youth centres and community centres
18	**University campus**	University campus	Lecture theatres, offices, workshops, eating places, laboratories and other activities	Weekdays and evenings	2660	Large floor space and variety of activities	Heating, lighting, cooling, office and teaching equipment	Laboratory, restaurant	Furnace or forming process	Typical campus mixes for further and higher education universities and colleges

A	B	C	D	E	F	G	H	I	J	K
	Name and description		Allocation guides				Further category details			
Cat	**Name**	**Brief description**	**Space usage**	**Operational schedule**	**Reference hours per year**	**Distinguishing features**	**Services included**	**Maybe part of mixed-use with areas below**	**Summary of allowable unique energy uses**	**Representative buildings**
19	**Clinic**	Health centres, clinics and surgeries	Provision of primary health care	Usually weekdays and early evenings	2040	Daytime use, essentially office hours, but needs to provide for high public use, generally by appointment	Heating, lighting, cooling, hot water services			Doctors surgeries, health clinics, veterinary surgeries, dentist
20	**Hospital; clinical and research**	Clinical and research hospital	Mainly space for medical care with 24-hour accommodation for patients, with associated operating theatres, laboratories, offices and workshops	Continuous for the majority of the facility	8760	24-hour accommodation with stringent environmental conditions, ventilation control, quarantine, and high occupant servicing needs	All services	Laboratory or operating theatre, restaurant	Furnace or forming process	Acute hospital, specialist hospital, teaching hospital and maternity hospital
21	**Long term residential**	Long term residential accommodation	Full accommodation, including sleeping space, daytime space, all domestic facilities, some office facilities	Continuous	8760	24-hour fully conditioned and serviced accommodation	Heating, lighting, cooling, appliances, food and hot water services, entertainment, laundry	Restaurant (dining hall)		Residential home, homeless unit, cottage hospital and long stay hospital, detention centres and prisons
22	**General accommodation**	General accommodation	Space for sleeping, showers, basic domestic services	Non-continuous occupancy, often only used in evenings	2940	Slow turnover of occupants requires fewer facilities and less laundry than for example a hotel	Heating, lighting, cooling, laundry and drying rooms			Boarding houses, university and school hostels, homeless units, nursing homes

A	B	C	D	E	F	G	H	I	J	K
	Name and description		**Allocation guides**				**Further category details**			
Cat	**Name**	**Brief description**	**Space usage**	**Operational schedule**	**Reference hours per year**	**Distinguishing features**	**Services included**	**Maybe part of mixed-use with areas below**	**Summary of allowable unique energy uses**	**Representative buildings**
23	**Emergency services**	Emergency services	Offices, accommodation, food services, cells, garaging and other activities as required	Normally continuous, some stations closed in the evenings and weekends	8760	Provision of a variety of services that would be in separate categories in other parts of the non-domestic stock (e.g. accommodation, offices and vehicle garaging)	Heating, lighting, cooling, food services, office and training equipment			Police, fire and ambulance stations
24	**Laboratory or operating theatre**	Laboratory or operating theatre	Special equipment and conditions in at least 30% of floor area	Either weekday or 24-hour multi-shift	2040	Spaces requiring controlled ventilation and conditions	Heating lighting, ventilation		Furnace or forming process	Research chemical laboratory, hospital operating theatre
25	**Public waiting or circulation**	Bus or train station, shopping centre mall	Public circulation or waiting facilities	Variable — intermittent to continuous	2040	Waiting and circulation areas, booking desks, boarding facilities	Heating, lighting, cooling, snack services	Retail		Bus stations, local train stations, shopping centre malls
26	**Terminal**	Regional transport terminal with concourse	Waiting and boarding facilities for air, ship or regional/international train travel	Daytime and evenings each day to near continuous	8760	Concourse and booking areas, identification, customs, security and baggage handling	Heating, lighting, cooling, baggage handlings	Retail, restaurant, covered car park		Large train stations, airport terminals
27	**Workshop**	Workshop or open working area (not office)	Facilities for light mechanical work	Generally working week but can be multi-shift	2040	Goods access, mechanical tools and facilities	Industrial heating and lighting standards		Furnace or forming process	Workshops, vehicle repair

A	B	C	D	E	F	G	H	I	J	K
Name and description			**Allocation guides**				**Further category details**			
Cat	**Name**	**Brief description**	**Space usage**	**Operational schedule**	**Reference hours per year**	**Distinguishing features**	**Services included**	**Maybe part of mixed-use with areas below**	**Summary of allowable unique energy uses**	**Representative buildings**
28	**Storage facility**	Storage warehouse or depot	Storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2040	Lightly serviced long-term storage areas	Low level lighting and heating in storage areas			Distribution warehouse without public areas, and local authority depot
29	**Cold storage**	Refrigerated warehouse	Refrigerated storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2660	Refrigerated long term storage areas	Refrigeration, lighting and heating of handling areas		Blast chilling or freezing plant	Refrigerated warehouse without public areas

3 METHODOLOGY

3.1 Introduction

As already highlighted, in Chapter two, EPCs are produced using standard methods and assumptions about energy use, in accordance with the exigencies of the EPBD [4], [5]. A qualified energy performance assessor conducts the building energy audit, collects all relevant data and carries out the analysis for issuing an EPC. All the input and output data are stored in a national central electronic database. In Malta, the standard calculations for estimating the building's energy demand are performed with SBEM-mt calculation software using the quasi-steady state monthly method [116]. The energy demand for the different non-residential buildings includes space heating, cooling, domestic hot water, auxiliary energy for HVAC, as well as the positive contribution of renewables, but it does not include plug loads or other engineering services. The rating label for ranking the building's energy performance is on a letter-scale and is given by comparing the building's calculated carbon dioxide emissions, known as the building emission rating (BER) against that obtained for a reference building, that is SER in $kgCO_2/m^2.year$. The reference building is an identical building to the actual model in terms of physical dimensions but having the minimum energy performance requirements of Technical Document F [16] automatically assigned to the characteristics of its building elements and technical installations to meet the minimum energy code requirements. It is to be noted that the SER of the SBEM-mt carries also a 20% improvement over the reference SER, given that the software was based on the old 2006 Technical Document F and it was already predicted that the minimum energy requirements would have to be improved by time.

Understandably, the AR does not predict how the actual building is going to perform, because this depends on other factors that may not be considered as standards, such as human behaviour, actual scheduling, set temperatures, climate change, and others. This possible source for the performance gap or discrepancy, may be an essential factor in actual energy use which consequently also affects important decisions.

The final aim of any EU Member State is to achieve carbon neutrality by 2050, as set in the 2050 long-term strategy of the EU [25]. This can only be achieved if the actual energy consumption in buildings tends to approach net zero-energy status. However, this is not always possible because buildings are either still being constructed or are required to be renovated and therefore the prediction of any software should nevertheless be realistic and reflect the expected energy demand as much as possible.

3.2 Methodology overview

The aim of this thesis is to better understand the performance gap for the case of Malta and provide solutions or alternatives that would better predict actual performance, which is the ultimate and only relevant figure upon which policies and plans may be made to achieve carbon neutrality.

The approach taken was to identify common criteria upon which the analysis may be carried out. After carefully observing a number of EPCs of different non-residential buildings, it was concluded that:

a. All EPC ratings are independent of the area of the building, because the reported BER and SER are given per useful unit total floor area.
b. Method for calculation of heating and cooling system energy requirements and system efficiencies are based on EN 15316-2-1[117].
c. All EPC ratings can be assumed to be quasi-independent of the internal volume because the floor to floor height is similar for all categories of buildings.
d. Lighting demand is a function of area and to a limited extent depends on solar natural light ingress.
e. Thermal and visual comfort within a space on the external boundary of the building are heavily affected by direct solar radiation for which the six-metre rule applies. Additional zoning will have to be introduced if the area of glazing in any external wall that is larger than 20% of the total wall area. This condition is not

always encountered unless the building has very large windows such as in showrooms or shops. Therefore, this energy demand will be relatively constant for all buildings, especially because there is only one solar energy weather file for the whole Maltese territory.

f. Water heating demand is a function of occupied floor areas only (such as area of offices, storage spaces, bedrooms, receptions, classrooms, wards, and workshops) and therefore, it would have a different but relatively constant value for each non-residential building category.
g. The only two energy demands that would significantly vary were found to be the heating, ventilation and air-conditioning (HVAC). Moreover, the energy demand for this sector takes up a large portion of the total energy demand of non-residential buildings.
h. Finally, in the case of HVAC, building categories in Malta may be classified into three distinct cluster groups:
    i. <u>Cluster type 1</u>: Elementary non-residential buildings, which are nearly free-running buildings or are very similar in their fabric to domestic premises and services present, such as schools or a block of shops with overlying apartments.
    ii. <u>Cluster type 2</u>: Non-residential buildings where comfort conditions need to be controlled utilising “frequently recurring actions," such as the use of simple small self-contained cooling and heating systems, with natural or forced ventilation, packaged domestic hot water generators, and natural as well as artificial lighting. Offices, shops and restaurants fall under this cluster type definition.
    iii. <u>Cluster type 3</u>: Complex buildings that have advanced features both concerning building envelope fabrics and services installations, often requiring multitasking and advanced control systems that are not found in the above two clusters. This category of buildings would usually use superior cooling and heating system for treatment and comfort needs including chillers, boilers, ducting, with primary and secondary systems,

as typically used in large hospitals, hotels, shopping malls and other extensive amenities.

The above clustering has been instrumental to manage this study within the time limitations available in a smart manner, thus ensuring that the analysis of EPCs are limited but at the same time span across all representative categories of buildings.

Given that educational, office and healthcare buildings cover up to 47% of the non-residential building stock in Europe [14], it was deemed sufficient to analyse the EPCs of these three categories of buildings each falling under one of the above clusters.

Schools in Malta are practically free-running buildings and thus fall in Cluster 1, while most offices are defined as small to medium buildings with independent split-type air-conditioning or variable refrigeration flow (VRF) units and therefore fall in Cluster 2. Finally, hospitals use more complex HVAC systems and therefore can represent Cluster 3.

Once this approach was concluded, a number of EPCs were sought to kickstart the analysis process. By comparing the EPC results to the actual energy consumption of these buildings readings from billing meters or when not possible analytically calculated based on the installed power and number of operating hours. Subsequently, the EUIs as generated by the EPCs software were compared to the actual as measured, or as calculated, on site to determine the extent of the performance gap.

3.3 Analysis of non-residential national energy rating certificates.

The above section summarised the methodology description for the first part of this thesis. In the following sections, the methodology is expanded to explain this first part. Later on, in Section 3.6, the second and third parts of the methodology are presented, which will lead to the ultimate solutions and fulfilment of the objectives.

3.3.1 EPC for Cluster type 1

For Cluster 1, the study carried out an analysis of all schools that had EPCs available, as provided by the Education Department of the Ministry for Education and Employment. These contained a relevant mix of large and small, primary and secondary schools, as well as new and old schools ranging between two and over fifty years old.

A sample of eleven schools was chosen to represent the whole population, as shown in Table 3-1.

Table 3-1: Detailed list of schools chosen

School/College	Location	**Cert.No.**	**Area**	**Primary Energy Use**	**CO_2 Emissions**	**EPC Rating**	date visited
			m^2	kWh/m^2yr	kg/m^2yr		
Gozo College	Gozo	64	1150	28	7	A	11/9/18
St Ignatius College	Ħandaq	17	10838	116	28	B	31/7/18
St Clare's College	Pembroke	44	5538	102	26	B	30/6/18
St Ignatius College	Ħandaq	75	14498	159	40	B	31/7/18
Maria Regina College	Mosta	21	7637	245	62	C	20/6/18
St Clare's College	Pembroke	31	11727	197	50	C	30/6/18
St Thomas More College	Żejtun	x	1649	131	33	D	7/9/18
St Benedict College	Mqabba	15	2505	164	42	E	7/9/18
Maria Regina College	Naxxar	26	1573	419	107	C	20/7/18
San Gorg Preca College	Blata l-Bajda	39b	6013	727	134	D	17/9/18
St Ignatius College	Qormi	79	5452	52	13	B	31/7/18

These were chosen to represent the different variables that were noted in the database of the whole population, such as the energy performance grades attained, the area and the age of the school.

All the above schools had their Nero Cover Design (NCT) file examined for *general suitability* to see that the basic input information was credible. The NCT file is read by iSBEM-mt where all the input data is stored [55]. It was not possible to go into the detailed checking of the dimensions of all rooms, windows, doors, shading, U-value verification, etc. as this would have required months of verification. Moreover, as highlighted in section 2.2.1 the quality assurance of such certificates is part of the duties of the methodology within the Building Regulation Office (BRO), who conducts periodical checks on samples of EPCs of every assessor to ensure that the process of issuing EPCs is appropriately followed and faithfully reproduced.

For these schools all the Excel or PDF files generated by SBEM were opened and examined and the data collected was plotted in tables and charts in preparation for data analysis, as detailed in Chapter four.

3.3.2 EPC Cluster type 2

For this cluster, it was difficult to find already existing EPCs due to lack of access to data and also because privately owned buildings are not required to have an EPC, unless they are up for sale or rent or are being newly constructed.

Therefore, the approach taken was to identify an office building that has all the typical features such as open-plan offices and separate offices, central and split-type air-conditioning system, as well as having part of it that is open for visits by the general public and thus analyse it. A modern fully functional office block was found, covering more than 4,400m^2 of useful floor, having over 282 full-time employees and being managed by an international company and a dedicated maintenance team. This building block was designed, and project managed by reputable local firms of architects and building services engineering consultants. It has a modern design and was built using latest technologies, fully air-conditioned with individual or open plan offices. The office block is self-contained, forming part of a building block that hosts another firm with separate lifts and circulation area.

A full walk-through audit, as well as an energy bill analysis was carried out to determine the required input parameters for the SBEM-mt software, as well as determine the actual energy consumption for the different uses (air-conditioning, lighting, water heating, ventilation, equipment). For this purpose, design drawings and specifications of installed equipment was sourced. Zone splitting, calculation of U-values, details of installed equipment and other data are given in a step-by-step procedure in Chapter four. Based on this information, the SBEM software was used and the whole building was input as different zones, in accordance with the SBEM methodology. The EPC was then generated and analysed.

3.3.3 EPC for Cluster type 3

For this cluster, and given that there are not many hospitals that have their EPC ready, the natural choice was to use that of the only general hospital Mater Dei, which holds more than 43% of available public beds in Malta [10].

The Mater Dei Hospital is an acute/ teaching 1,000-bed general hospital. Its build was completed in 2007 and it opened as the general hospital soon after. Its build approach was managed and designed by an international reputable firm, to the National Health Service (NHS) Standards of the United Kingdom. The hospital covers a total useful floor area of over 250,000m^2, which was built under strict state-of-the-art specifications and a built process which included:

- an integrated design team;
- optimised energy efficient brief;
- optimised plant selection;
- effective use of building management (BMS) controls;
- intricate handover; and
- computerised maintenance management programmes (CMMS).

It operates on a 24-hour basis throughout the year, in a fully controlled air-conditioned hospital environment with twenty-four operating theatres, fully equipped intensive therapy units (ITU), cardiac intensive care unit (CICU), central sterile service department (CSSD), out-patient department, imaging and laboratory departments and a medical school. It was commissioned in 2007 and cost more than 600 million Euro. Over the years, it has shown a very stable energy use inertia. For this last point, analysis will be dealt with in Chapter four.

The EPC for this hospital was produced in 2015 by a local firm of building services engineering consultants. The EPC asset rating was made on a sample of part of the actual building but extrapolated to the whole building and the certificate and its rating was registered in the national database that is held by the Building Regulation Office (BRO).

This EPC will be used and compared to the results of analysis of all energy consumption of the hospital for 3 consecutive years, in order to answer some of the research questions. In other words, the SBEM-mt energy use intensity in kWh/m².year will be compared to the actual EUI over three years.

3.4 Calculation methodologies of actual energy consumption

For each cluster, the research went on to calculate the actual energy consumption onsite.

3.4.1 Actual energy used for Cluster type 1

In schools and other similar Cluster type 1 buildings, there is only a single electricity meter that measures the cumulative energy consumption. Therefore, the only way to know the actual sectoral energy consumption for space heating, space cooling, lighting, water heating and ventilation was to carry out detailed site walk-through audits for all equipment, their power rating and time of use.

Therefore, each school was surveyed for all its plugged-in equipment such as computers, printers, photocopiers, interactive white boards, lathes, cookers, fridges, canteen equipment etc., as well as all other equipment such as fans, lights, lifts, air-conditioners and external lighting. A scientific assessment of their consumption was made. Individual equipment power loads were taken from their nameplates and a loading factor was applied on the actual absorbed energy, based on established methods as given in Chapter eighteen of *2009 ASHRAE Handbook – Fundamentals* [105].

The exact equipment operating hours were calculated based on questionnaires and feedback from interviews with precincts officers, heads of schools, and teachers. Schools in Malta open from 7.30am till 2.30pm for nine months, five days per week, with 5.75 student hours per day. This works out at around 1,365 hours per year of operation. However, the final equipment load was harmonised to reflect the total schooling hours as per education department schedule for that year, which also allowed for public holidays.

It is to be noted that from the onsite survey, only four schools out of eleven could be analysed, because the electricity meters of the other schools were at the substation and they could only read the total energy consumed by all buildings that are connected to that specific sub-station. Therefore, it was not possible to segregate the energy consumption of the school from the total energy consumption.

The four schools that were analysed were:

1. St Ignatius College, Ħandaq Middle Secondary (built in 2013).
2. St Ignatius College, Ħandaq Secondary School (built in 2007)
3. Maria Regina College, Mosta Secondary School (built late 1960s)
4. St Clare's College, Pembroke Secondary School (Early 1900s)

The above schools 1 and 2 were combined on a weighted area average as they were being fed from the same Enemalta substation using a single electricity meter.

As seen above, although the number of schools to be analysed was reduced, they still represent different eras of construction methodologies, but they still have similar use and operational scheduling.

3.4.2 Actual energy used for Cluster type 2

The energy consumed in this office building was all electrical and in view that it was rented as fully furnished, it had adequate metering for space heating and cooling consumption of main plant outdoor units, which consisted of 16 independent two-pipe variable refrigeration flow (VRF) heat pump units. However, for other equipment such as indoor fan coil units, split individual AC units, fresh air supply and extractor fans, lighting and domestic hot water boilers, the electric loads had to be calculated by multiplying the installed power by an efficiency factor and the number of working hours, as provided by the maintenance department for each zone. With regards to small individual units which are generally installed in infrequently used offices such as board rooms or meeting rooms, it was assumed that their consumption varies sinusoidally with the outside climatic conditions [118]. The installed power was multiplied by a root mean square (RMS) value of 0.55, to reflect the reduction in load during the lee months, when consumption is lower.

3.4.3 Actual energy used for Cluster type 3

The readings taken from actual electrical energy meters could only be read from each of the five 11,000/400VAC electrical substations, which were not segregated to enable comparison to SBEM-mt results. Therefore, the following approach was carried out for the years 2014, 2015 (when the EPC was produced) and 2016, as follows:

- Surveying and auditing all the installed equipment on site and allocating them to each of the five categories of SBEM-mt for cooling, heating, auxiliary (pumps, air handling units, fan coils, ventilation fans, etc.) domestic hot water and lighting.
- Data was carried from the installed BMS in terms of output in chilled or hot water production and absorbed currents, running hours etc. from which, the actual energy consumed could be calculated to a high degree of accuracy.

3.5 Determination of the gap

Once all the data was prepared for the three clusters of buildings, a detailed exercise was carried out to identify the gap at a macro-level i.e. on the level of EUIs, as well as on the micro-level of separate analysis for space heating, space cooling, water heating, lighting and auxiliary energy consumption. In doing so, it is possible to understand better from where this gap is emanating.

The gap that one needs to identify should also consider whether there is a specific trend or whether it is sporadic. In other words, one needs to find out whether all of the three clusters have a gap between the actual energy consumption and that reported in the EPC and whether this gap is always negative or positive or varying for the different clusters.

Another important point to consider is to understand if the EPC is giving realistic results. In other words, whether a well-designed building gives a good EPC and a less-well designed would give a worse EPC or vice-versa.

In case that a gap exists, one has to identify methods that would provide a way forward, so that Malta can produce reliable and representative energy performance projections and benchmarks for non-residential buildings. The best solution may well be to opt for the actual consumption readings, averaged over a three-year period. Such a solution requires workable meaningful benchmarks, whereby EUIs are prepared beforehand using rigorous procedures that are based on good practice energy efficiencies related to the design and operation of non-residential buildings.

The ultimate scope is for EU members states to achieve lower carbon emissions and this can be realistically monitored through the use of actual energy consumption rather than simulations by EPC software. However, this energy consumption also needs to be compared to a benchmark for that particular building category, so that there will be a differentiation between low and high efficiency non-residential buildings. This is the approach that is being proposed in the next section.

3.6 Proposing an alternative route

As explained in Chapter two, it is understood that substantial energy consumed in buildings, especially for air-conditioning, is primarily dependent on the outside weather conditions, as well as Malta's geographical position on the globe, which is in relation with the sun's path as shown in Figure 3-1.

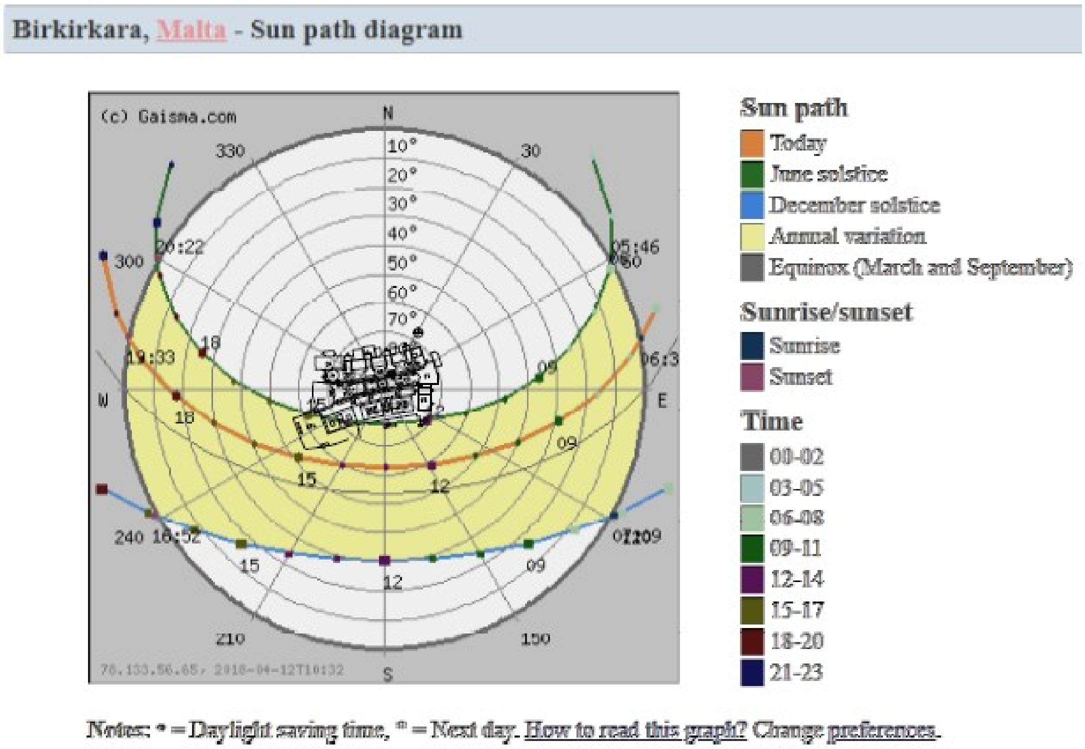


Figure 3-1: Typical yearly sun-path for Malta showing the daily period of solar radiation, in relation to case study Cluster building type 3 [119]

On the other hand, although the energy performance of buildings is very important, given that non-residential buildings in Malta consume more than 26% of the total imported fuel consumption, the number of certificates issued so far is not sufficient to create a statistical benchmark for each category of buildings.

For the purpose of establishing benchmarks, one must have smartly designed and constructed buildings which at least are:

- responsive to the requirements of occupants, organisations and society;
- sustainable in terms of energy and water consumptions;
- low polluting in terms of emissions and waste;
- healthy in terms of wellbeing for the people living and working within them and;
- functional according to the user needs.

At this point in time such readily constructed buildings are difficult to find locally for all types of non-residential buildings. Besides, using highly sophisticated methods to come up with the benchmarking for energy consumption for each building type requires specialised expertise, time and financing.

However, as discussed in the previous chapter and as shown in Figure 2-19, the energy use signature in buildings is practically the same for all buildings across the world and depends on a part which is weather-independent and is influenced by the class, type of design, operation and maintenance, while the remaining part of energy use is weather-dependent to achieve inside thermal comfort [61].

On a positive note, as shown in the previous chapter for the UK, USA and South Korea, the procedure for issuing the Display Energy Certificates is based on the actual energy consumption, or in other words on the Operational Rating certificate, rather than the Asset or Design Rating certificates. The determination of benchmarks for the OR is based on the Degree Day Method. This relates to the energy required by the building transfer functions equated to the difference between the internal environment temperatures and an outside agreed, or standard, base temperature [120].

The DD method [105] is a good method for energy analysis and is appropriate if the building's use and HVAC equipment efficiency are generally constant. Consumption can be calculated for different values of outdoor temperatures and multiplied by the corresponding number of hours and DD as a function of the assumed base temperature.

The notion of Heating Degree Days (HDD) may be formulated by considering the energy balance on a building shown schematically in Figure 3-2.

Equating the rates of energy gain and rates of energy loss, one can calculate:

Solar Gain + Internal Gain + Heating System Output = Transmission Heat Loss + Ventilation Heat Loss [121]

$$\mathbf{Q} + \mathbf{G} = \mathbf{H}\,(\mathbf{T}_i - \mathbf{T_o}) \quad \text{(W)} \tag{3-1}$$

Where each represents:

G	The sum of solar and internal gains (lights, personnel, etc) [W]
Q	Heat system output [W]
H	Transmission + ventilation losses rate per °C of internal to external temperature difference [W/K]
T_o	the external temperature [°C]
T_i	the internal temperature [°C]

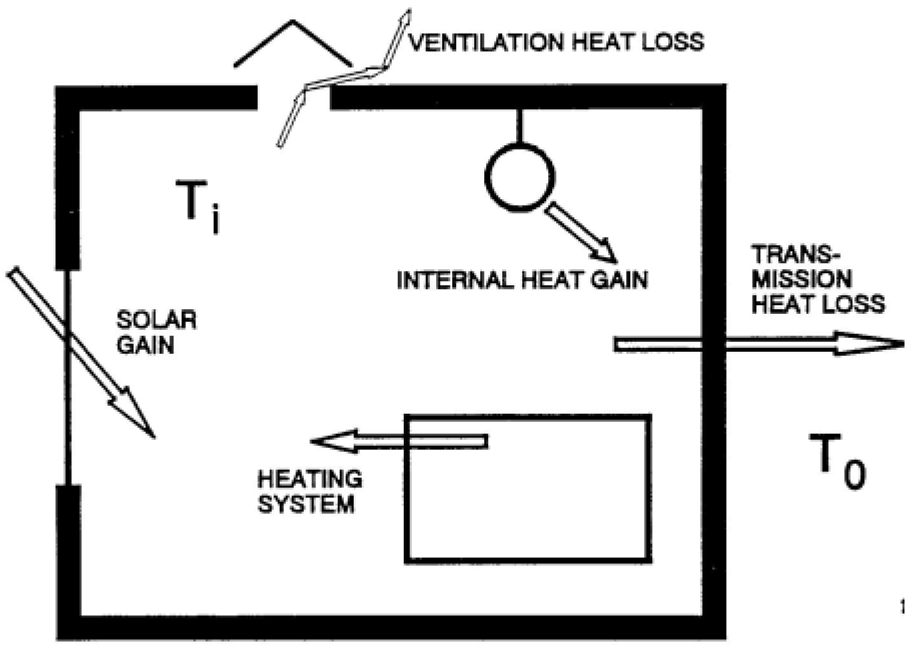


Figure 3-2: Energy flow transfers in a building

$$\mathbf{Q} = \mathbf{H}\,(\mathbf{T}_i - \mathbf{T_o}) - G \quad \text{(W)} \tag{3-2}$$

$$\mathbf{Q} = \mathbf{H}\left(\mathbf{T}_i - {}^{G}/_{H} - \mathbf{T_o}\right) \quad \text{(W)} \tag{3-3}$$

The new quantity introduced here is the base temperature [121]

T_b (°C)

$$\boldsymbol{T_b} = \boldsymbol{T_i} - {}^{G}/_{H} \qquad (\,^{O}c) \qquad (3\text{-}4)$$

This reflects the fact that the base temperature can also be interpreted as the balance point external temperature at which a building requires neither heating nor cooling, in order to provide comfortable conditions for its occupants. For continuous operation under steady conditions over N days, the energy supplied by the heating system can be calculated [121] as shown in Equation (3-5)

$$\mathbf{24NQ} = \mathbf{24HN}\,(\mathbf{T}_b - \mathbf{T_o}\,) = 24HDD \qquad \text{(Wh)} \qquad (3\text{-}5)$$

Where the number of DD has been [121] introduced (3-6):

$$\mathbf{DD} = \mathbf{N}\,(\mathbf{T}_b - \mathbf{T_o}\,) \qquad \text{(K-days)} \qquad (3\text{-}6)$$

Note, that 24 changes from instantaneous power in Watts, to a daily energy consumption of Watt hour.

In words, this can be stated as the extent to which external temperature falls below base level over x number of days for which this applies.

For the case of the UK, the DD was based on the HDD only, because it is a predominantly heating country with 2021 HDD with an associated base temperature of 15.5°C. The cooling degree-days being less than 50 cooling degree days (CDD) were ignored.

On the other hand, for predominantly cooling countries such as Malta, the calculation of the cooling energy consumption using the degree day method is more complex, because as opposed to the case for heating, where windows are generally assumed to be closed, the situation for a climate like that of Malta where seasons are clearly staggered, would require the opening of windows during mid-seasons and this could actually help in postponing the use of air-conditioning for cooling.

Another issue associated with computing the energy required for calculating the cooling degree days is the latent load. While in heating the energy associated with the moisture content of air (latent load) is not considered, since this moisture of the infiltrating or ventilating air is generally considered as an asset for the comfort of the occupants during heating, this is not the case during cooling, which would require additional cooling energy consumption. This is a variable quantity and whatever method is used, one has to ensure that it is capable of considering the air ventilation or leakage rates for the building in the category, and be able to calculate the unit energy consumption and adjust it to the operational benchmarks.

Therefore, the method implemented in this dissertation to calculate the degree days requires following the steps below:

a) Calculate the degree days for Malta based on HDD base temperature of 15.5^{o}C and CDD of 18.5^{o}C taken from the ISE station at Marsaxlokk. These were harmonised, checked and verified after carrying an averaging process with international stations [105] [108], over a three-year period 2010, 2016 and 2017. The year 2010 was chosen because it is the year that the weather file of SBEM-mt is built on. For the Summer period degree-hours were preferred to reflect only the time the cooling plant is in operation [105]. However, in predominantly cooling load countries where the main cooling plant is intermitted operated only when cooling is required, Degree-hours make much more sense to calculate the energy consumption during this period.
b) Guidelines, as given in EN16798 for indoor air quality, were considered for low polluting buildings and non-adapted personnel indoors, based on the Predicted Mean Vote and Percentage of people dissatisfied (PMV and PPD are given in ISO 7730 [122].
c) EN16798 also suggests a second step for the calculation of the required airflow rates, based on the amount of CO_2 present in indoor space in relation to a variable limit commonly used as an overall proxy for contamination and lack of adequate ventilation. However, such application would require the introduction of CO_2 concentration sensors and variable speed fan motors to vary the ventilation rates according to the indoor CO_2 levels. Such a procedure for dimensioning of energy use should come at a later stage, when proposing installation improvements.

d) The required air flow rate for the different 29 categorised non-residential buildings benchmarks, was based on typical occupation densities as found in standard guidelines such as those adapted for fire standards detailed in Chapter four.

e) For each categorised building, the EUI associated with the difference in the moisture content of inside to outside air was calculated from data provided by the Meteorological Office of the Malta International Airport weather station. It is necessary to pay attention to the latent load only when the cooling plant is in operation, the meteorological data hourly readings were filtered for each categorised benchmark daily and weekly operating schedules for the years 2016 to 2018, after filtration for base temperature above 18.5^{o}C.

f) Then for each categorised building the difference in moisture content energy load was calculated from the formulae as given in ASHRAE Fundamentals Handbook [105] using the given dewpoint temperature to calculate the outside air vapour pressure which in turn was then used to calculate its moisture content.

g) On the other hand for each categorised building the internal moisture content was determined by averaging the recommended comfort room temperatures and relative humidity (RH) as given in EN16798 and CIBSE Guide A [123], and values were read from psychrometric charts.

h) The difference in moisture content (absolute humidity) between the outside air and the internal spaces multiplied by the airflow rate as calculated in item (b) above gave the unit latent load related to each categorised building for the time of summer operation per unit useful area as shown in Chapter four.

i) Thus, the above steps would succeed in transforming the 29 UK energy benchmarks for non-residential buildings to equivalent benchmarks that are adapted to the local Maltese climate, by adjusting for the weather conditions through the degree day method, as well as by taking into consideration the added latent load due to water content associated with the respective ventilation airflow rates.

3.7 Testing of benchmarks

The final step of this thesis will be to test the validity of the calculated benchmarks with the actual energy consumption results of the three cluster non-residential buildings, namely schools, office and hospital. This comparison will serve as a verification process to build the required confidence in the proposed benchmarks for good practice non-residential building categories. Once validated, these benchmarks will serve as reference points on which other buildings within the appropriate category can be compared to gauge their level of energy efficiency and whether there are further opportunities for improving their operational rating. Subject to approval by the relevant authorities, the results can also be used as benchmarks for general policy making or for the Display Certificates that all public buildings, which are frequently visited by the general public, are required to place at the entrance door.

3.8 Summary

This chapter presented a quantitative methodology that is used to check if a performance gap exists between the energy used as predicted by the EPC to that actually measured on site. Once established, an alternative approach is proposed based on literature review and on established standards to produce benchmarks for 29 different categories of non-residential buildings which in turn can fit 237 different types of buildings, taking into consideration the effect of the climate and the added latent load, due to the water content in ventilated air.

By this, Malta would have adequate yardsticks upon which non-residential buildings can measure their energy performance, as well as estimate the extent of the potential for further energy efficiency they can achieve. Furthermore, the proposed benchmarks will be useful to adopt in any future Operational Rating certificates, based on actual energy consumption of these non-residential buildings.

4 DATA COLLECTION AND ANALYSIS

4.1 Introduction

This chapter will focus on the data collection and analysis of the first and second parts of this thesis analysis of the EPC and the actual energy consumption of the three non-residential clusters will be determined to identify the performance gap and gauge its extent. The three clusters are schools, offices and hospitals, which together form 47% of the total floor area of non-residential buildings in the EU [30].

4.2 Cluster type 1 buildings - schools

4.2.1 The buildings and engineering services

In this case study, several Energy Performance Certificates as prepared by registered assessors on SBEM for several state schools in Malta and Gozo, were studied and compared to the actual energy consumption generally worked out from the utility bills.

State schools in Mata are generally built in the traditional Maltese way of architecture with a preference for low buildings made of Maltese limestone, which gives buildings their typical honey-coloured characteristic. Their facades are generally in double globigerina limestone, locally known as *tal-Franka* with an air gap but no insulation in between. Roofs are generally constructed in cast concrete with no insulation except for waterproofing. Windows are generally in a single glass with wooden or aluminium frames, sometimes with Venetian blind structures for shading. Some are relatively new, but others dated back to more than 40 years ago. However, when visited they were relatively well maintained, and maintenance was usually carried out in summer during the holidays.

Schools operate within similar daily schedules as in the UK, the source location for the original SBEM. Schools open from 7.30am till 2.30pm for nine months, five days per week with 5.75 student hours per day as given in Table 4-1 from the Education Department circular 2015/ 64a [124].

Table 4-1: Total hours of local schooling for years 2015/2016 [124]

Month	Year	No. of Student Days in the Month	No. of Hours Primary per Day	Total Hours in the Month	No. of Hours Secondary per Day	Total Hours in the Month
September	2015	3	5.5	16.50	5.75	17.25
October	2015	22	5.5	121.00	5.75	126.5
November	2015	19	5.5	104.50	5.75	109.25
December	2015	15	5.5	82.50	5.75	86.25
January	2016	17	5.5	93.50	5.75	97.75
February	2016	18	5.5	99.00	5.75	103.5
March	2016	16	5.5	88.00	5.75	92
April	2016	21	5.5	115.50	5.75	120.75
May	2016	22	5.5	121.00	5.75	126.5
June	2016	20	3.75	75.00	3.75	75
Sub total		**173**	-	**916.50**	-	**954.75**

As already mentioned earlier, Cluster 1 buildings such as schools, are the simplest in the non-residential categories, since in Malta they generally lack the comfort of any continuous cooling, heating, forced ventilation or any specialised domestic hot water systems.

4.2.2 Analysis of the SBEM-mt EPCs of schools

As mentioned in the Methodology chapter, the eleven schools were chosen in such a way so as to be as representative as possible of the whole population. When looking at the 87 EPCs that were available at the time, the choice of the schools took into consideration their rating, the total floor area and their age.

The SBEM-mt NCT files were uploaded on the software and checked for any errors. As shown in Figure 4-1, it was already obvious that Table 4-2 certificate 64 for Gozo San Lawrenz School had such a good grade of “A” rating because of the installation of a 35kWp photovoltaic system on its roof. On the other hand, the abnormally high consumption of domestic hot water for certificate 39 for San

Georg Preca College at Blata l-Bajda could not be overlooked and had to be analysed in further depth. At this stage, it was noticed that the school was wrongly classified as a boarding school. However, when corrected it did not make much difference to the output of hot water energy consumption. This was not as expected since boarding schools consume much more domestic hot water, generally in the same range as hotels.

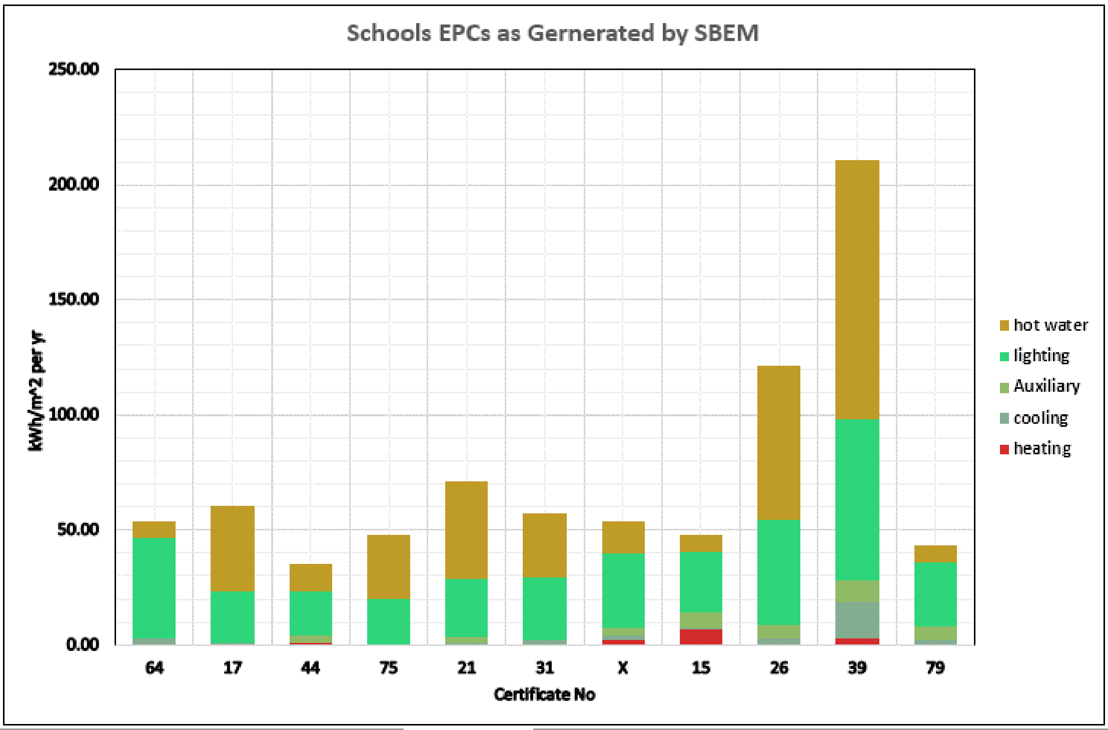


Figure 4-1: Graphical representation of 11 schools' generated EPCs services

In such a case, one must note the importance, as highlighted in section 2.2, for due diligence from the assessors and the vigilant quality checks required when analysing and checking the EPCs by the authorities.

Table 4-2: Summary of EPCs of chosen schools

College		San Lawrenz, Primary School	St Ignatius College, Ħandaq Secondary	St Clare's College, Pembroke Primary School	St Ignatius College Middle School, Ħandaq	Secondary School, Maria Regina College	St Clare's College, Pembroke Secondary School, Sandhurst Block	St Thomas More College Primary School	St Benedict College, Mqabba Primary School	Naxxar Secondary School, Block B	San Gorg Preca College, Block C and E	San Gorg Preca College, Block C and E	Qormi San Gorg Primary
Certificate No		**64**	**17**	**44**	**75**	**21**	**31**	**X**	**15**	**26**	**39**	**39 (b)**	**79**
Location		**Gozo**	**Ħandaq**	**Pembroke**	**Ħandaq**	**Mosta**	**Pembroke**	**Żejtun**	**Mqabba**	**Naxxar**	**Blata l-Bajda**	**Blata l-Bajda**	**Qormi**
EPC Rating		**A**	**B**	**B**	**B**	**C**	**C**	**D**	**E**	**C**	**D**	**G**	**D**
Area (m^2)	**m^2**	1,150	10,838	5,538	14,498	7,637	11,727	1,629	2,505	1573	6,013	6,013	5,452
CO2 Emissions	kg/m²yr	7	28	26	40	62	50	47	42	107	185	431	169
Primary Energy Use	kWh/m²yr	28	116	102	159	245	197	186	164	143	727		149
Unit Annual Energy Consumption		**kWh/m² .yr.**											
System		**Actual (BER)**											
Heating		0.25	0.18	0.86	0.16	0.15	0.34	2.01	6.48	0.06	2.84	2.84	0.36
Cooling		2.89	0.74	0.27	0.15	0.46	1.63	2.42	0.69	2.50	16.20	16.20	1.57
Auxiliary		0.01	0.00	3.15	0.00	2.71	0.00	3.33	7.14	6.14	8.93	8.93	6.05
Lighting		43.64	22.72	19.02	20.02	25.43	27.42	32.09	26.26	45.91	70.13	70.13	27.90
Hot water		7.34	36.93	11.88	27.65	42.41	27.85	14.03	6.99	66.90	112.61	393.15	7.39
Total		**54.13**	**60.57**	**35.18**	**47.99**	**71.16**	**57.24**	**53.88**	**47.57**	**121.51**	**210.70**	**141.64**	**43.28**
Renewables		**kWh/m² .yr.**											
PVS		45.92	1.92	5.63	2.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wind		0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CHP		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		**45.92**	**1.92**	**5.68**	**2.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**

4.2.3 Actual site measured and estimated energy consumption

In Malta, the engineering services of such buildings are not designed to cater for segregated electrical services for cooling, heating, and ventilation, lighting and domestic hot water. In such cases in analysing this performance gap, one must compute the annual electricity consumed and subtract from it the energy used for small power such as computers, printers, copiers cookers, fridges, lifts, workshop tools, etc. Thus, what remains gives energy consumption as projected by SBEM-mt.

In order to achieve this purpose, all eleven schools were visited and surveyed to note all the equipment in use and gain insight to their operational strategies. However, after visiting the sites, it was found that from all the 11 schools, only 4 could be analysed and compared thoroughly mainly because the Enemalta energy meter readings for the other schools were not available on the individual block or were combined with other ancillary buildings that do not form part of the school.

Where necessary, individual equipment power ratings were taken from their nameplates and a loading factor was applied on the actual consumed energy, based on research results for computers and kitchen cooking appliances, as given in Chapter eighteen of the ASHRAE Handbook – Fundamental [125].

On the other hand, energy performance for lifts was worked from ISO/DIS 25745-1: *Energy performance of lifts and escalators – Part 1* [126].

Consequently, the four schools analysed were:

1. St. Ignatius College - Ħandaq Middle School (certificate 75);
2. St. Ignatius College, Ħandaq Secondary School- (certificate 17);
3. Maria Regina College Mosta Secondary School (certificate 21);
4. St. Clare's College, Pembroke Secondary School, Sandhurst Block - (certificate 31).

Schools 1 and 2 had to be combined as one site because they were both fed from the same Enemalta substation with one energy meter. These are two relatively modern buildings with fully functional facilities and well maintained, as shown in aerial view Figure 4-2 below. Between them, they have the following equipment:

- 7 photocopiers;
- 14 desktop computers;
- 14 printers;
- 125 classrooms;
- 8 computer labs;
- 8 home economic labs;
- 5 engineering & technology labs;
- 5 staff rooms;
- 6 passenger lifts;
- 2 canteens; and
- 16 outside lighting features.

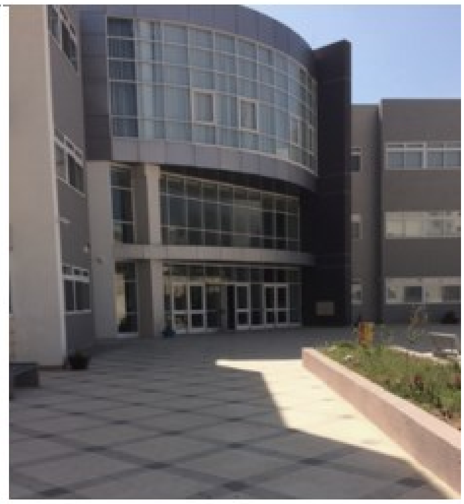


Figure 4-2: Ħandaq Secondary and Middle schools - St Ignatius College [54]

As shown in Table 4-3, an example of calculation for the Ħandaq Secondary school is shown. When all the above-weighted nameplate power equipment was multiplied by the daily student hours' time to the schedule as given by the Education Department, less the assumed idling time, one can obtain the total annual energy consumed of 153,724kWh.

Table 4-3: Part of calculated energy consumption for equipment at the Ħandaq Middle School

College		**St Ignatius College Middle School, Ħandaq**									
School								Floor area	14,498	m^2	
Equipment				**Power Consumption W**		**Daily usage**	**Months**	**Unit Annual hourly usage**		**Total Annual Consumption**	**Comments**
Item		Qty		**nameplate power**	**Average power**	Hrs	No	**full**	**idle**	**kWh**	
Administration											
Photo copiers		**5**	**No**	**1850.0**	**1060 idle 305**	**7.00**	**9**	**450**	**901**	**3,761**	**Idle two thirds**
Desktop		**10**	**No**	**740.0**	**84.0**	**7.00**	**9**	**780**	**585**	**714**	**Idle 3-hour 10W**
Printers		10	**No**	**508.0**	**98.0**	**7.00**	**9**	**780**	**585**	**823**	**Idle 3-hour 10W**
Classrooms		**75**	**No**								
	IAOs + projector	**1**	**each**	**1650.0**	**434.0**	**5.75**	**9**	**780**	**293**	**27,583**	**Idle 1.5-hour 100W**
Computer labs		**5**	**No**								
	IAOs + projector	1	each	**1650.0**	**434.0**	**5.75**	**9**	**780**	**293**	**1,839**	**Idle 1.5-hour 100W**
	PC desktop	16	each	**740.0**	**84.0**	**5.75**	**9**	**780**	**293**	**95**	**Idle 1.5-hour 100W**
	Total									**9,668**	For 4 labs
Home economics lab		**4**	**No**								
	Fridges	3	each	365	145	3.00	9	819	0	356	3 hrs per day whole full year yr.
	Display oven	1	No	1495	1200	6.00	12	1,040	390	1,482	2 hrs idle at half capacity
	Display fridge	2	No	1407	352	6.00	12	1,040	390	869	2 hrs idle at half capacity
	Microwave	1	No	3194	3194	6.00	12	1,040	390	3,945	2 hrs idle at half capacity
	Electric oven	3	No	12000	12000	6.00	12	1,040	390	44,460	2 hrs idle at half capacity
	Drinks dispenser	2	No	1400	500	6.00	12	1,040	390	1,235	2 hrs idle at half capacity
	Total									**52,786**	for 1 canteen
To continue till end of sheet on similar procedure											
Outside Lighting		**10**	**No**								
	Halogen lamps	1	No	1000	1000	10.00	12	3,640	0	**36,400**	10 hrs a day all year
GRAND TOTAL PROJECTED ACTUAL ENERGY CONSUMPTION PER YEAR							**for school hours**		**1,365**	**219,950**	**kWh**
Projected Annual Energy consumption as per Education department circular 2015/ 64a							**for school hours**		**954**	**153,724**	**kWh**

A similar exercise was done on the Ħandaq Secondary school, which gave an annual electrical equipment energy consumption amounting to 79,052kWh. When both consumptions were added together on a weighted average according to their areas, this gave a unit electrical consumption load of 4.81kWh/m^2.yr, as shown in Table 4.4 below. This area-weighted average considers the annual energy consumption for such loads if both schools were one but on the same usable trends.

Table 4-4: Unit weighted average of calculated energy consumed for both schools – St. Ignatius College, Ħandaq

School	St Ignatius College, Middle School - Ħandaq	St Ignatius College, Secondary School - Handaq	Total
Area m^2	14,498	10,838	25,336
Weighted Average of Projected Energy Consumption by Power Rating and Operating Hours			kWh per year
Corrected Projected Annual Energy consumption for Middle school as per Education department circular 2015/ 64a			153,724
Corrected Projected Annual Energy consumption for Secondary school as per Education department circular 2015/ 64a			79,052
Unit weighted combined consumption per floor area of both Middle and Secondary schools)			121,781
Unit weighted combined consumption per floor area of both schools (kWh/m² yr)			**4.81**

Furthermore, as shown in Table 4-5, the electricity bill for the past 20 months was practically all estimated except for two periods: Ending on 18 December 2015 and 4 March 2016, respectively. In this case, the sites were visited again on 29 October 2018, and revised. An instantaneous reading was taken from the Enemalta meter amounting to 1,639,170 kWh.

Table 4-5: Arms Ltd. billing for 2015 ~ 2017

College	**Ħandaq Middle School, Ħandaq**		**Ħandaq Secondary School, Ħandaq,**	
School	Floor area	**14,498 m²**	Floor area	**10,838 m²**

Actual Readings taken from ARMS Ltd. bills 2015~2016

Meter no.	**Period bills kWh ("N" being not read – estimated)**										Total
1010 0002 4904	19-SEP-2015 – 18-DEC-2015	19-DEC-2015 – 06-JAN-2016	07-JAN-2016 – 04-FEB-2016	05-FEB-2016 – 04-MAR-2016	04-MAR-2016 – 06-APR-2016	07-APR-2016 – 06-MAY-2016	07-MAY-2016 – 06-JUN-2016	07-JUN-2016 – 06-JUL-2016	07-JUL-2016 – 05-AUG-2016	06-AUG-2016 – 06-SEP-2016	
Consumption	10,254	N 147500	N 145,394	24,988	N 25000	N 22727	N 23485	N 22727	N 22727	N 24242	0

Actual Readings taken from ARMS Ltd. Bills 2016~ 2017

Meter no.	**Period bills kWh**										Total
1010 0002 4904	07-SEP-2016 – 06-OCT-2016	07-OCT-2016 – 04-NOV-2016	05-NOV-2016 – 06-DEC-2016	07-DEC-2016 – 06-JAN-2017	07-JAN-2017 – 06-FEB-2017	07-FEB-2017 – 06-MAR-2017	07-MAR-2017 – 11-APR-2017	07-APR-2017 – 11-MAY-2017	06-MAY-2017 – 10-JUN-2017	07-JUN-2017 – 11-JUL-2017	
Consumption	N 22727	N 21969	N 24242	N 23484	N 150374	N 24002	N 23485	N 21970	N 24243	N 22727	0

Taking this instantaneous value and working on the conservative side in favour of SBEM, the total annual average electrical consumption for 365 days was found to be about 372,071kWh, which gave a unit loading of 14.69kWh/m^2.yr, as shown in

Table 4-6 below.

Table 4-6: Total annual energy consumed for the two schools

		reading set 1		reading set 2	
meter reading as on		19/09/2015	29/10/2018	04/03/2016	29/10/2018
Meter reading kWh	kWh	447,522	1,639,170	778,980	1,639,170
No of Days	No		1,169		1,002
Difference	kWh		1,191,648		860,190
total for 365 days	kWh per yr		372,071		313,343

Total floor area	m^2	25,336
Total Annual Energy Consumption for School	kWh	372,071.45
Unit Energy Loading	kWh/m^2	14.69

Consequently, by calculating the equipment electrical unit loading at 4.81kWh/m^2.yr and subtracting from 14.69 kWh/m^2.yr, the figure of 9.88 kWh/m^2.yr can be determined and compared to SBEM-mt. This is the total energy consumed from space heating and cooling, water heating, lighting and ventilation.

4.2.4 Gap analysis for Cluster type 1 buildings.

The two EPC readings of 47.99 and 60.57Wh/m^2.yr for both secondary and middle schools, respectively were added together and averaged on their weighted areas, as shown in Table 4-7. The average was found to be 53.37kWh/m^2.yr.

However, when this was compared to the actual electricity readings worked out from onsite analysis, SBEM was found to be heavily overrating the predicted energy consumed, by 5.4 times as shown in Table 4-7.

Table 4-7: Comparison of SBEM to Energy measured on site for St Ignatius College

College		St Ignatius College Middle School, Handaq	St Ignatius College, Secondary School, Handaq	Total weighted average for both schools
Location		Tal-Ħandaq	Tal-Ħandaq	
EPC Rating		B	B	
Area (m^2)	m^2	14,498	10,838	25,336
CO2 Emissions	kg/m²yr	40	28	35
Primary Energy Use	kWh/m²yr	159	116	140
Unit Annual Energy Consumption		kWh/m^2 .yr.	kWh/m^2 .yr.	Total
System		(BER)	(BER)	kWh/m^2 .yr.
Heating		0.16	0.18	0.17
Cooling		0.15	0.74	0.40
Auxiliary		0.00	0.00	0.00
Lighting		20.02	22.72	21.17
Hot water		27.65	36.93	31.62
Total		47.99	60.57	53.37

Renewables	kWh/m^2 .yr.		kWh/m^2 .yr.
PVS	2.01	1.92	3.92
Wind	0.00	0.00	0.00
CHP	0.00	0.00	0.00
Total	2.01	1.92	3.92

	MJ/m^2 .yr.		
SES (solar heaters)	0.21	0.00	0.21
TSC	0.00	0.00	0.00

Actual Consumption	Electricity	Fuel	Comments
Total annual Enemalta bills (kWh/m^2 .yr)	14.69	0	SBEM highly over-rated by
Projected Total Equipment consumption (kWh/m2 .yr)	4.81	0	
Difference to compare to SBEM (kWh/m^2 .yr)	9.88	0	
Percentage of SBEM Gap			540%

The same exercise was repeated for the Maria Regina College Secondary school, Mosta and St Clare's College Secondary School, Pembroke, and again SBEM was found to be systematically overrating the energy consumed by 12.66 and 5.18 times, respectively, as shown in Table 4-8 below.

Overall, on the four colleges, SBEM gave a total area weighted overrated energy consumption of more than six times as shown in Table 4-8.

Table 4-8: Overall comparison of SBEM rating to that measured on site for the four colleges

College		St Ignatius College, Ħandaq Middle & Secondary Schools	Secondary School, Maria Regina College	St Clare's College Secondary School, Sandhurst Block	
Certificate No		17 &75	21	31	
Location		Ħandaq	Mosta	Pembroke	
EPC Rating		B	C	C	
Area (m^2)	m^2	25,336	7,637	11,727	
CO2 Emissions	kg/m²yr	35	62	50	
Primary Energy Use	kWh/m²yr	140	245	197	
Unit Annual Energy Consumption		kWh/m² .yr.			Projected Total Average on Area
Heating		0.17	0.15	0.34	0.21
Cooling		0.40	0.46	1.63	0.74
Auxiliary		0.00	2.71	0.00	0.46
Lighting		21.17	25.43	27.42	23.54
Hot water		31.62	42.41	27.85	32.48
Total EUIs as given by SBEM		53.37	71.16	57.24	57.42
Total electrical use intensity as measured on site		14.49	14.66	18.50	15.57
Total electrical use intensity as calculated for site equipment		4.81	9.04	7.05	6.12
Total electrical use intensity allowed for SBEM comparison		9.88	5.62	11.05	9.46
Percentage over rating of SBEM		540%	1266%	518%	607%

4.2.5 Discussion

One cannot fail to note that even if the recorded total bill of electrical energy consumption of 15.57kWh/m^2.yr were to be allocated solely for SBEM-mt energy sectors, this still would have shown that SBEM prediction at 57.42kWh/m^2.yr would still be more than 3.6 times overrated. This is undoubtedly not the case, as the small power equipment such as interactive white boards, office equipment, computers, home economic and technology labs together with canteens, workshops, lifts etc. are important for such schools and are necessary for teaching.

One must note that in this exercise the intention was to see the functionality of SBEM-mt methodology in both the software and the results achieved. In such a case, it was not the intention to see where the errors are. Although the EPCs were generally overviewed, this was done for general suitability and not to go into the most important aspects, or practical details inputted such as the U-values, thermal mass, etc., since it was assumed that such assessors are well knowledgeable trained engineers and architects, and the raw data was not made available for any detailed quality checks. These remain the property of the assessors.

Also, as can be seen in Figure 4-1, all eleven schools except for certificate 39 for St George Preca College are in the same scenario, and one cannot overlook the high prediction of domestic hot water energy consumed.

This excessive consumption is highly irregular and abnormal because in Malta such schools practically have limited domestic hot water services in their taps.

From such overrating results for such simple buildings, which practically are without any engineering services, it can be easily concluded that the SBEM structure has some serious shortcomings.

In Malta, having practically short mild winters with hot and humid summers, seasons are well staggered and practically constant. One cannot fail to comment on the deficiency of the electricity provider in providing regular short periodic bills. The absence of such bills cannot help the consumer to be aware of the energy use and analyse it to take the necessary steps for correction in case of over-consumption. In fact “Awareness” is a dominant theme in ISO 50001 Energy Management Systems [106] used for lowering of energy consumption and increasing energy efficiency.

4.3 Cluster type 2 Buildings – A large office block

4.3.1 The building

The place was built in the early 2000s and is mainly located in a semi-industrial zone with a modern style of architectural features. This office block contrasts sharply with the adjacent more traditional ones, in a practically unshaded development. The plan has a rectangular shape and has about one-third of its private area shared with another business firm having a separate entrance, permanent dividing walls; and separate systems and metering.

It is a two-storey building, each storey measuring circa 65m x 34m and built on a slope along its short axis on top of a third-party carpark. The carpark also houses the main electrical power incomers and the main electrical switchgear panels with metering sections. The carpark is managed as a separate entity and as such was not considered to be part of this study.

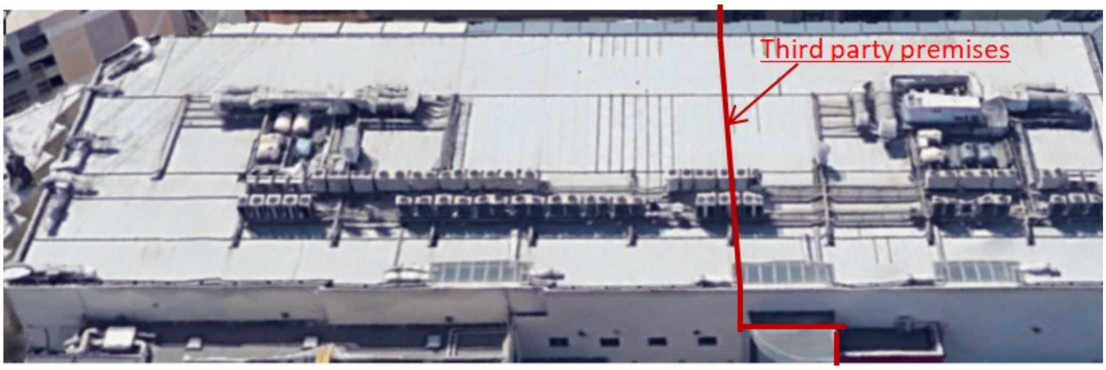


Figure 4-3: Layout of the office building

Nearly all the HVAC plant is installed on the roof as shown in Figure 4-3, and the building is mainly used for active day-to-day business interaction with the public, as well as back-end administrative activities, all operating within a pleasant modern environment with closed window setup. The first floor is accessible by an external lift and stairs near the main entrance, while two more lifts are situated within the building. The building may be categorized as a heavy construction, built on reinforced concrete columns and beams. The facade is in double layer walls of 150mm thick concrete blocks with 50mm air gap in between having an overall U-value of 1.09W/m^2 K. The floors are made of cast concrete with suspended soffit and gypsum partitioning walls of low thermal mass as shown in Table 4-9 below.

Table 4-9: Schedule of building material used

Construction Material

Item	Type	Density	U-Value	Thermal mass
		kg/m²	W/m²K	kJ/m²K
External Wall	Ext plaster + Solid block + Air gap + Hollow brick + Int. plaster	845.50	1.09	133.71
Internal wall	Ext plaster + Hollow brick + Int plaster	418.00	0.46	133.74
Internal partitioning	Light plaster + 25mm gypsum board + 50mm void + 25mm gypsum board + Light plaster	45.00	1.61	18.90
Roof	19mm Soffit tile + Void + 225mm cast concrete + 80mm *torba* + 80mm screed + WP membrane	764.82	0.87	4.73
Ground Floor Slab	Tile + 80mm *torba* + 225mm cast concrete	703.50	1.99	108.43
First Floor Slab	Tile + 80mm *torba* + 225mm cast concrete + Void + Soffit tile	709.62	0.94	103.88
Ceiling on Ground	19mm soffit tile + void + 225mm cast concrete + 80mm *torba* + 25mm tile	709.62	0.93	4.73
Glazing	Aluminium frame + double 4-12-4mm uncoated glass - Air filled with thermal break	-	3.62	T Solar - 0.76 L Solar - 0.80
Doors	Wooden	-	3.00	-

4.3.2 The engineering systems

4.3.2.1 Air-conditioning

Both floors of this building are air-conditioned by 16 independent two-pipe variable refrigeration flow (VRF) heat pump units for either cooling or heating by reverse cycle, with cassette type indoor units and axial fans condensing units installed at roof level. They are all interconnected with insulated refrigeration copper pipework and wired wall-mounted averaging controllers for automatic operation. Each set of units has a centralised time controller for automatic operation on a pre-set time switch and mode of functioning.

In areas where the mode of operation was envisaged to be different from the open plan scenarios, such as kitchen/dining, boardrooms, manager's offices, and electrical rooms, separate split or multi-split air-conditioning units of the reverse cycle heat pump type are installed, thus giving better flexibility. Further details are shown in Table 4-10 below.

Table 4-10: Schedule of AC units installed

Name	Serving Zone		Make	Model	Heating		Cooling		Indoor units	
					Capacity kW	EER	Capacity kW	COP	Type	Qty
AC1 (Board Room)	Z0/	3	Hitachi	Utopia G7 407C	13.85	2.49	13.19	2.88	cassettes	2
AC2 (Elec. Room)	Z0/	10	Hitachi	Utopia G7 407C	10.77	2.49	10.26	2.88	wall mount	2
AC3 (Elec. Room)	Z1/	20	Hitachi	Utopia G7 407C	9.23	2.49	8.79	2.88	wall mount	1
AC4 (Mr S Office)	Z1/	23	Hitachi	Utopia G7 407C	12.31	2.49	11.72	2.88	cassettes	1
AC5 (communication room)	Z0/	5	Hitachi	Utopia G7 407C	10.77	2.49	10.26	2.88	wall mount	2
AC6 (Reception)	Z0/	1a,1b	Hitachi	Utopia G7 407C	7.69	2.49	7.33	2.88	concealed	2
AC7 Kitchen	Z0/	4	Hitachi	Utopia G7 407C	7.69	2.49	7.33	2.88	cassettes	1
AC8 Manager Office	Z0/	11	Hitachi	Utopia G7 407C	10.77	2.49	10.26	2.88	cassettes	1
AC9 Manager Office	Z0/	12	Hitachi	Utopia G7 407C	10.77	2.49	10.26	2.88	cassettes	1
HVAC System 1 (1/J)	Z0/	2a,2b,2c,2d,2e,2f,2g,2h,2i,2j	Hitachi	RSA24FSN	77.50	3.77	69.00	3.52	cassettes	12
HVAC System 2 (1/I)	Z0/	14	Hitachi	RSA18FSN	56.00	4.08	50.00	4.04	cassettes	7
HVAC System 3 (1/H)	Z0/	14	Hitachi	RSA18FSN	56.00	4.08	50.00	4.04	cassettes	7
HVAC System 4 (1/G)	Z0/	13, 14	Hitachi	RSA16FSN	50.00	3.24	45.00	3.12	cassettes	6
HVAC System 5 (1/F)	Z0/	13, 14	Hitachi	RSA16FSN	50.00	3.24	45.00	3.12	cassettes	6
HVAC System 6 (1/E)	Z0/	13, 14	Hitachi	RSA16FSN	50.00	3.24	45.00	3.12	cassettes	6
HVAC System 7 (1/D)	Z0/	13, 14	Hitachi	RSA16FSN	50.00	3.24	45.00	3.12	cassettes	6
HVAC System 8 (2/A)	Z1/	2, 3, 5, 6, 7, 8, 9, 10	Hitachi	RAS24FSN	77.50	3.77	69.00	3.52	cassettes	10
HVAC System 9 (2/B)	Z1/	24	Hitachi	RAS28FSN	80.00	3.30	90.00	3.82	cassettes	6
HVAC System 10 (2/C)	Z1/	24	Hitachi	RAS24FSN	77.50	3.77	69.00	3.52	cassettes	6
HVAC System 11 (2/D)	Z1/	24	Hitachi	RAS24FSN	77.50	3.77	69.00	3.52	cassettes	8
HVAC System 12 (2/E)	Z1/	24	Hitachi	RAS20FSN	63.00	3.48	56.00	3.90	cassettes	7
HVAC System 13 (2/F)	Z1/	16	Hitachi	RAS14FSN	45.00	3.49	40.00	3.30	cassettes	6
HVAC System 14 (2/G)	Z1/	16	Hitachi	RAS14FSN	45.00	3.49	40.00	3.30	cassettes	6
HVAC System 15 (2/H)	Z1/	22	Hitachi	RAS8FSN	25.00	4.12	22.40	4.08	cassettes	3
HVAC System 16 (2/I)	Z1/	17	Hitachi	RAS10FSN	31.50	4.07	28.00	3.78	cassettes	3
Total					**911.50**		**832.40**			**105.00**

4.3.2.2 Ventilation system

All areas are positively ventilated by 19 in-line duct mounted centrifugal fans and connected with round flexible ducting to each VRF indoor cassette unit for a total capacity of 15,000 m^3/hour, as shown in Table 4-11 below.

Table 4-11: Schedule of supply fans installed

Ref	Serving		Design air flow		Design ESP	Size	Inst power	Abs Power	SFP
		Zone	m³/hr	l/s	Pa	mm dia	W	W	W/ l/s
Ground Floor									
SF1	Z0/	4, 5, 6	500.0	138.9	75.0	150.0	165.0	123.8	0.9
SF2	Z0/	14	900.0	250.0	100.0	250.0	220.0	165.0	0.7
SF3	Z0/	14	900.0	250.0	100.0	250.0	220.0	165.0	0.7
SF4	Z0/	14	700.0	194.4	100.0	250.0	220.0	165.0	1.8
SF5	Z0/	13	700.0	194.4	100.0	250.0	220.0	165.0	0.9
SF6	Z0/	13	700.0	194.4	100.0	250.0	220.0	165.0	0.9
SF7	Z0/	14	700.0	194.4	100.0	250.0	220.0	165.0	0.9
SF8	Z0/	1a,1b,2a 2b,2c,2d,2e,2f,2g,2h,2i,2j,2k 3,15	1500.0	416.7	100.0	315.0	650.0	487.5	1.2
First Floor									
SF9	Z1/	2, 3, 4, 5, 6, 7, 8, 9, 10	1500.0	416.7	125.0	315.0	650.0	487.5	1.2
SF10	Z1/	14a, 14b, 14c	1000.0	277.8	100.0	315.0	650.0	487.5	1.8
SF11	Z1/	11, 12, 13	950.0	263.9	125.0	315.0	650.0	487.5	1.9
SF12	Z1/	16	350.0	97.2	100.0	150.0	165.0	123.8	1.3
SF13	Z1/	16	700.0	194.4	100.0	250.0	220.0	165.0	0.9
SF14	Z1/	16	350.0	97.2	100.0	150.0	165.0	123.8	1.3
SF15	Z1/	17	750.0	208.3	100.0	250.0	220.0	165.0	0.8
SF16	Z1/	24	700.0	194.4	100.0	250.0	220.0	165.0	0.9
SF17	Z1/	23, 24	700.0	194.4	100.0	250.0	220.0	165.0	0.9
SF18	Z1/	24	700.0	194.4	100.0	250.0	220.0	165.0	0.6
SF19	Z1/	24	700.0	194.4	100.0	250.0	220.0	165.0	0.9
TOTAL			15,000	4,166				4,301	

Similarly, all restrooms, changing rooms and ablutions are negatively ventilated through 4 inline duct-mounted centrifugal fans with ceiling mounted extract grilles for a total extract air of 4,200 m^3/hour, as shown in Table 4-12 below. As a result, there is overall positive pressurising of around 10,800m^3/hour of excess treated air, which usually finds its way to the outside through exfiltration, when doors are opened.

Table 4-12: Schedule of extract fans installed

Ref	Serving		Unit air flow		ESP	Model	Inst power	Abs Power	SFP
	Zone		m^3/hr	l/s	Pa		W	W	W/ l/s
Ground Floor									
EF 1	Z0	7a, 7b, 7c	1000.0	277.8	75.0	315.0	650.0	487.5	1.8
EF2	Z0	6, 7a,7b,7c,	1000.0	277.8	100.0	315.0	650.0	487.5	1.8
First Floor									
EF3	Z1	14a, 14b, 14c	1000.0	277.8	75.0	315.0	650.0	487.5	1.8
EF4	Z1	6, 11, 12, 13	1200.0	333.3	100.0	315.0	650.0	487.5	0.9
TOTAL			**4,200.0**	**1,166.7**				**1,950.0**	

Figure 4-4 below shows the first floor HVAC layout, with cassettes ceiling mounted indoor units with rigid fresh air ducting from supply fans, connected with flexible ducting to indoor units to give a uniform distribution. This gives an insight into the current installed system.

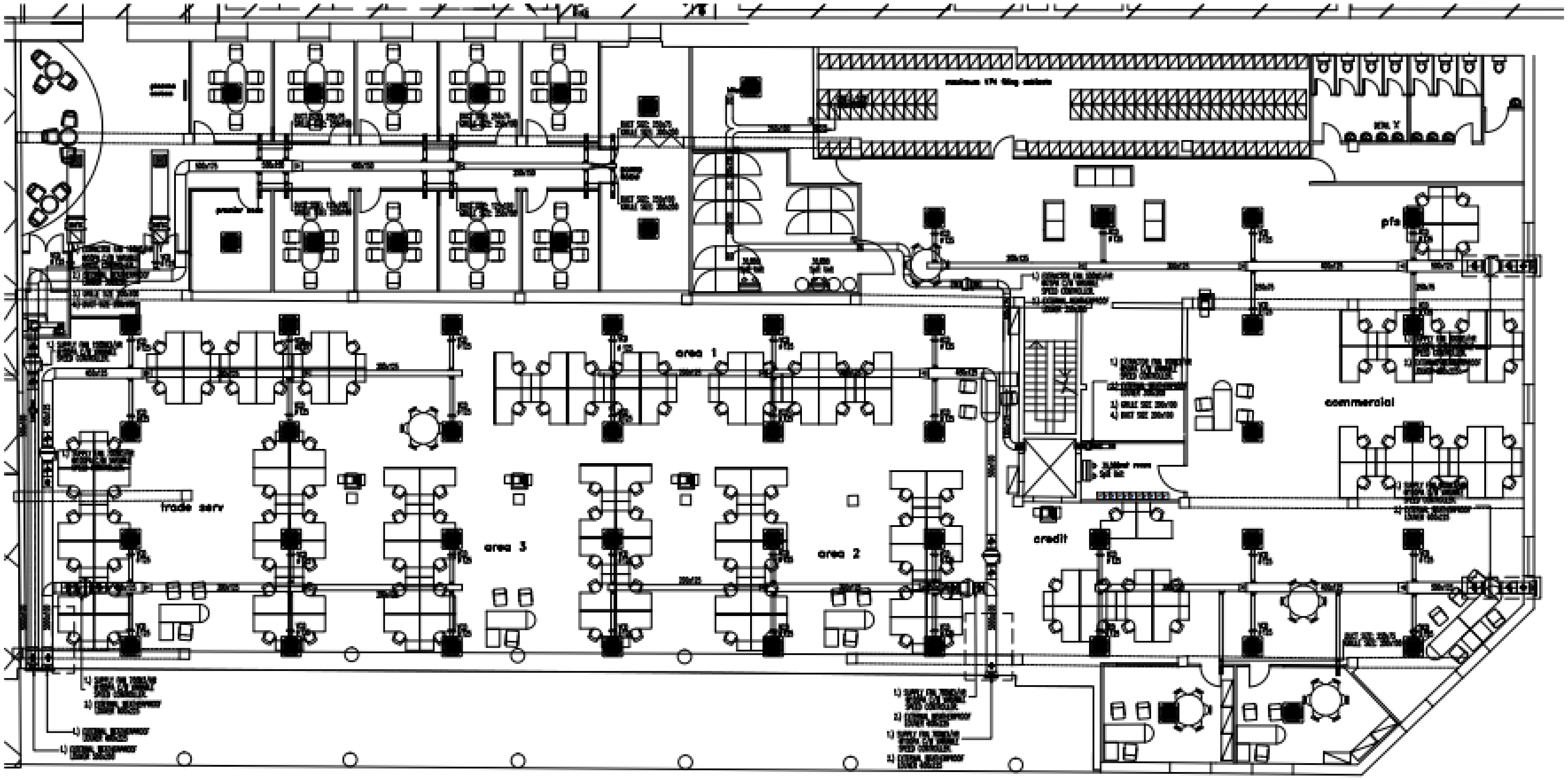


Figure 4-4: Typical layout of HVAC installation at ground floor

4.3.2.3 Domestic Hot Water System (DHWS)

The domestic hot water is provided by 4 independent and dedicated electric hot water boilers of different capacities, as shown in Table 4-13 below, to serve sanitary ware in a single pipe configuration but with no return pipework.

Table 4-13: Schedule of dedicated hot water boilers installed

Ref	Installed in	Type	Capacity	Energy source	Recovery	Electrical load
	Zone		Litres		Hours	kW
HWS	Z0/05	Stand alone	20.00	Electricity	2.00	0.57
HWS	Z0/08	Stand alone	50.00	Electricity	2.00	1.43
HWS	Z1/10	Stand alone	50.00	Electricity	2.00	1.43
HWS	Z1/15	Stand alone	20.00	Electricity	2.00	0.57
total			**140.00**			**4.01**

4.3.2.4 Lighting design

Initially, before the installation, a lighting design was carried out according to the furniture layout for general luminosity at the working plane of 500 Lux in all office spaces, while in other circulation areas, corridors, storerooms, and restrooms, this was lowered to around 200 lux. Artificial lighting was achieved by generally using PL lamps or T5 fluorescent luminaries with high-frequency ballasts, as shown in Table 4-14 below, with manual switching in all other areas but no occupancy sensors.

Table 4-14: Schedule of light fittings installed in ground and first floors

Zone		Lighting GF					
Ref	Activity	Lamp	Unit Power			Quantity	Total Inst Power
		Type	Qty		W	No	kW
Ground Floor							
Z0/01a	Waiting area	Halogen spot	2	x	18	21	0.756
Z0/01b	Reception	Halogen spot	2	x	18	10	0.36
Z0/02a	Meeting Rooms	PL light	2	x	18	4	0.144
Z0/02b	Meeting Rooms	PL light	2	x	18	4	0.144
Z0/02c	Meeting Rooms	PL light	2	x	18	4	0.144
Z0/02d	Meeting Rooms	PL light	2	x	18	4	0.144
Z0/02e	Meeting Rooms	PL light	2	x	18	4	0.144
Z0/02f	Meeting Rooms	PL light	2	x	18	4	0.144
Z0/02g	Meeting Rooms	PL light	2	x	18	4	0.144
Z0/02h	Meeting Rooms	PL light	2	x	18	4	0.144
Z0/02i	Meeting Rooms	PL light	2	x	18	4	0.144
Z0/02j	Meeting Rooms	PL light	2	x	18	4	0.144
Z0/02k	Corridors	PL light	2	x	18	5	0.18
Z0/03	Board Room	PL light	2	x	18	10	0.36
Z0/04	Kitchen	Fluorescent T5	4	x	14	6	0.568
Z0/05	Communication rm	Fluorescent T5	2	x	35	9	0.63
Z0/06	Filing room	Fluorescent T5	4	x	14	10	0.56
Z0/07a	Toilet	PL Light	2	x	18	6	0.216
Z0/07b	Toilet	PL Light	2	x	18	4	0.144
Z0/07c	Toilet	PL Light	2	x	18	2	0.072
Z0/08	Circ./lift area	PL Light	2	x	18	4	0.144
Z0/09	Stores	Fluorescent T5	4	x	14	1	0.056
Z0/10	Electrical room	Fluorescent T5	2	x	35	2	0.14
Z0/11	Manager's office	Fluorescent T5	4	x	14	5	0.28
Z0/12	Manager's office	Fluorescent T5	4	x	14	4	0.224
Z0/13	Open plan office	Fluorescent T5	4	x	14	48	2.688
Z0/14	Open plan office	Fluorescent T5	4	x	14	148	8.288
Z0/15	Toilets	PL light	2	x	18	1	0.036
Z0/16	Corridors	Fluorescent T5	4	x	14	4	0.224

Zone		Lighting FF					
Ref	Activity	Lamp	Unit Power			Quantity	Total Inst Power
		Type	Qty		W	No	kW
First Floor							
Z1/01	Circ. area	Halogen Spot	2	x	50	2	0.072
Z1/02	Reception	LV light fitting	1	x	5	17	0.17
Z1/03	Meeting Room	PL Light	2	x	18	4	0.144
Z1/04	Printing Room	florescent T5	4	x	14	2	0.11
Z1/05	Board Room	fluorescents T5	2	x	18	8	0.34
Z1/06	Mess Facility	florescent T5	4	x	14	4	0.22
Z1/07	Meeting room	PL Light	2	x	18	4	0.14
Z1/08	Meeting Room	PL Light	2	x	18	4	0.14
Z1/09	Meeting Room	PL Light	2	x	18	4	0.14
Z1/10	Meeting Room	PL Light	2	x	18	4	0.14
Z1/11	File Storage Room	fluorescents T5	4	x	14	8	0.45
Z1/12	File Storage Room	florescent T5	4	x	14	12	0.67
Z1/13	File Storage Room	fluorescent T5	4	x	14	6	0.34
Z1/14a	Toilets	PL Light	2	x	18	6	0.22
Z1/14b	Toilets	PL Light	2	x	18	5	0.18
Z1/14c	Toilets	PL Light	2	x	18	1	0.04
Z1/15	Offices	fluorescent T5	4	x	14	29	1.40
Z1/16	Offices	fluorescent T5	4	x	14	41	2.30
Z1/17	Offices	fluorescent T5	4	x	14	18	1.01
Z1/18	Lift / Stairs	PL Light	2	x	18	4	0.14
Z1/19	Stationery Room	florescent T5	4	x	14	1	0.06
Z1/20	Electrical Rm	fluorescent T5	2	x	35	1	0.07
Z1/21	Corridor	florescent T5	4	x	14	3	0.17
Z1/22	Offices	fluorescent T5	4	x	14	8	0.45
Z1/23	Manager's Office	PL Light	2	x	18	8	0.29
Z1/24	Offices	florescent T5	4	x	14	111	6.22
Z1/25	Corridors	PL Light	2	x	18	6	0.22
Z1/26	Corridors	PL Light	2	x	18	5	0.18

4.3.3 SBEM-mt input data & rating

4.3.3.1 Geometry

This EPC of the office had to be done completely, as it was not available. This was initiated by inputting the geometry into SBEM-mt software, where each floor was subdivided into indexed zones as per SBEM-mt methodology requirements, as shown in Figure 4-5 and Figure 4-6 below. Each area was zoned and distinguished from all others in contact with it, by one or more of the following conditions:

- physical separation by an envelope (wall);
- Activity within it;
- HVAC system;
- lighting system;
- ingress of natural daylight.

For each zone, dimensional parameters on its area, height, type and orientation of walls, glazing, doors, ceilings and floors, construction of adjoining spaces and percentage of glazing and shading were computed. This data was tabulated as partly shown in Table 4-15 below and inputted into the "Building Geometry" information tab as requested by SBEM.

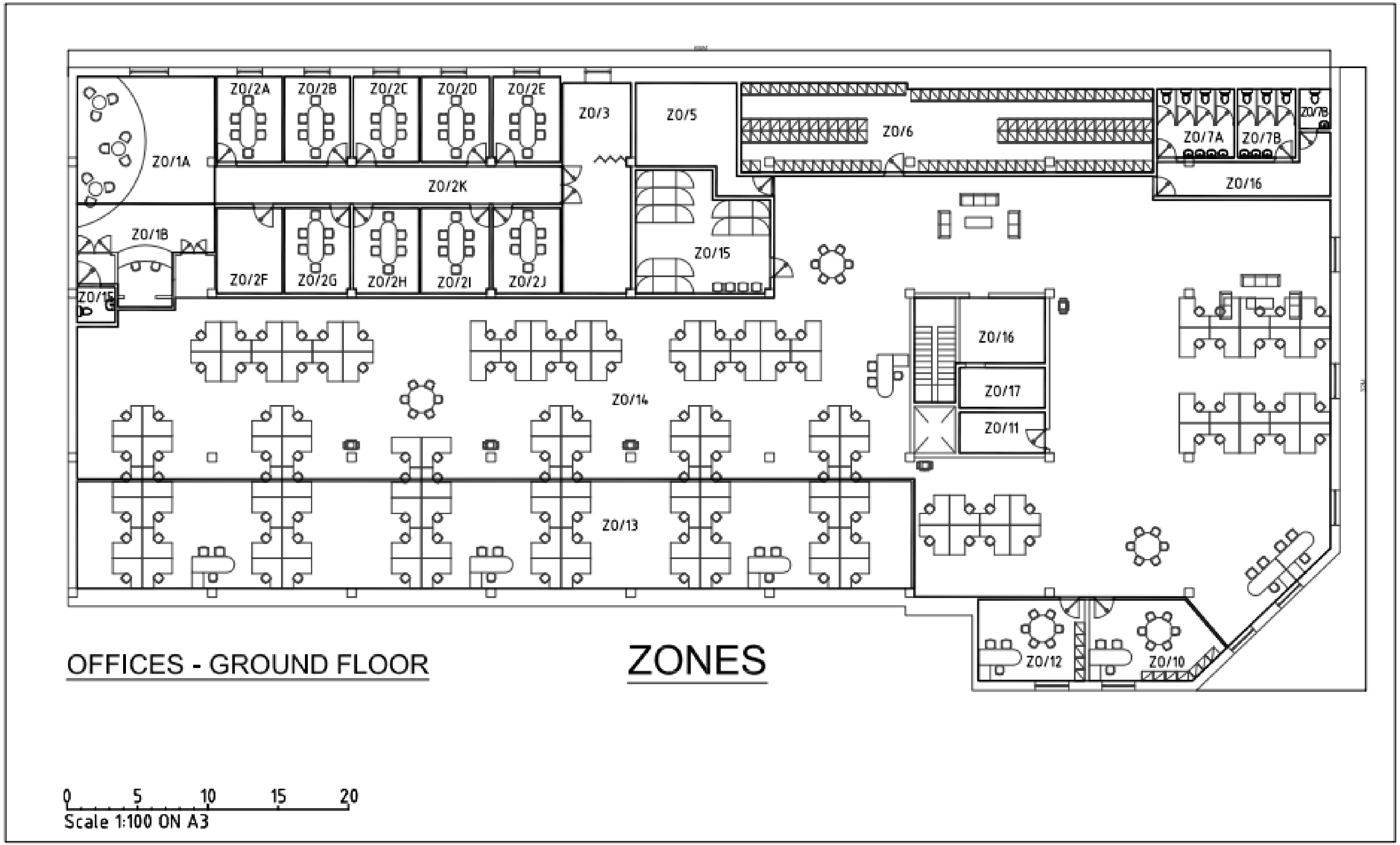


Figure 4-5: Ground floor zoning of the office under study (Cluster 2)

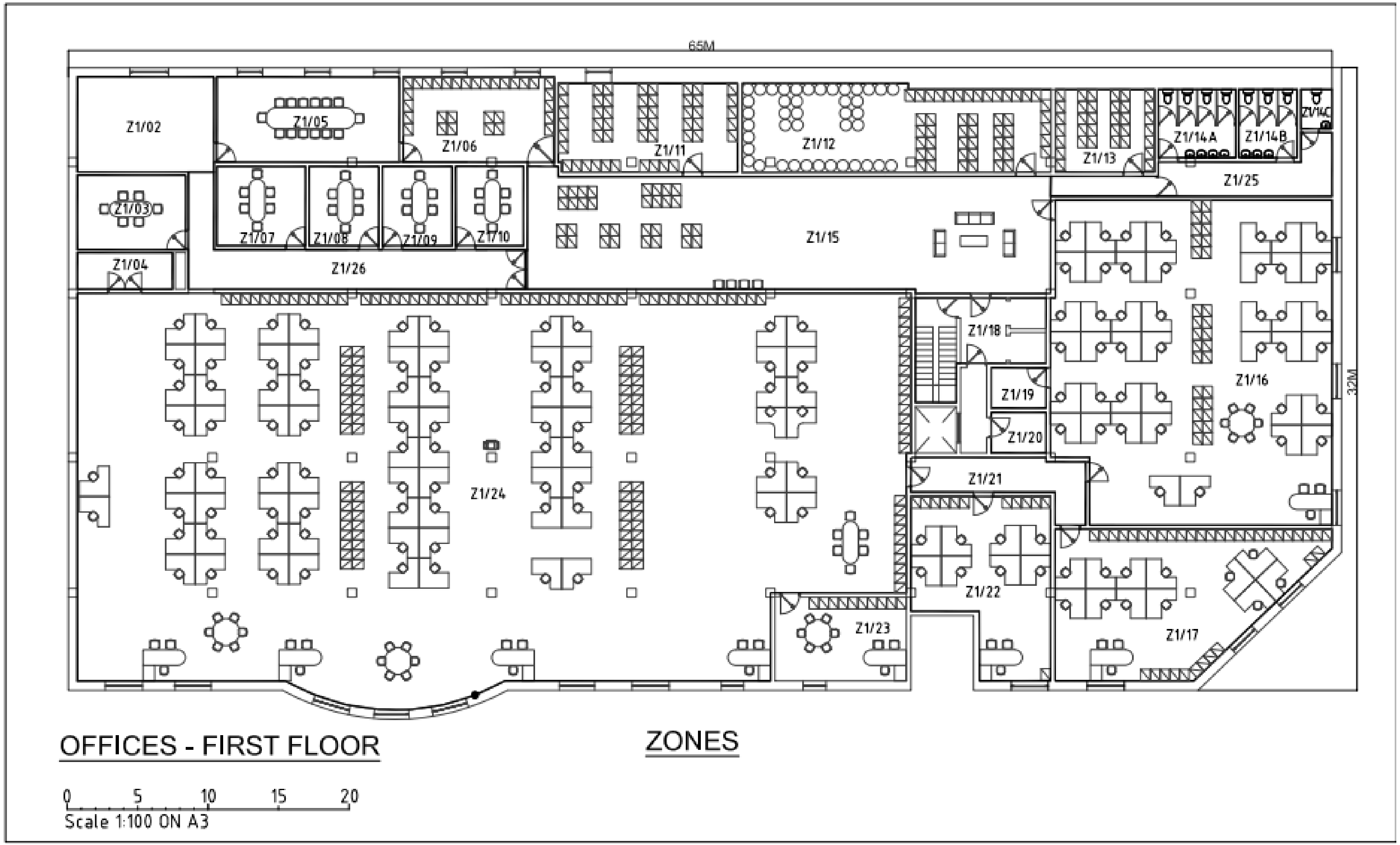


Figure 4-6: First-floor zoning of the office under study (Cluster 2)

Table 4-15: Part schedule showing zones with construction materials of envelopes

Ground Floor

Zone			Envelopes				Windows/Doors	
Ref	**Activity**	**Area m²**	**Ref**	**Area m²**	**Length m**	**Assignment**	**Item**	**Area m²**
z0/01a	Waiting area	42.00	z0/01a/ne	13.00	7.00	Exterior	z0/01a/ne/g	8.00
			z0/01a/se	18.00	6.00	Interior	-	
			-	-	-	Interior	-	
			z0/01a/nw	18.00	6.00	Exterior	-	
			z0/01a/f	42.00	-	floor	-	
			z0/01a/ci	42.00	-	ceiling	-	
z0/01b	Reception	28.00	-	-	-	-	-	
			z0/01b/se	15.00	5.00	Interior	-	
			z0/01b/sw	17.00	7.00	Interior	z0/01b/sw/d	4.00
			z0/01b/nw	12.00	4.00	Exterior	-	
			z0/01b/f	28.00	-	floor	-	
			z0/01b/ci	28.00	-	ceiling	-	
z0/02a	Meeting rooms	12.00	z0/02/ne	5.00	2.00	Exterior	z0/02/ne/g	1.00
			z0/02/se	12.00	4.00	Interior		
			z0/02/sw	4.00	2.00	Interior	z0/02/sw/d	2.00
			z0/02/nw	12.00	4.00	Interior	-	
			z0/02/f	-	12.00	floor	-	
			z0/02/ci	-	12.00	ceiling	-	

4.3.3.2 Building Services

Once the building geometry data was completed and inputted in SBEM, the information on the building services installed was gathered and input in the appropriate building services tabs in global or zonal configurations, as shown in Table 4-16 below. This included:

- HVAC systems – including information on the type of systems in use, fuel in use, type of the central plant, cooling and heating seasonal efficiencies, duct leakages, type of controls, building pressurisation, and specific fan powers (SFP);
- HWS systems - including information on the type and capacity of hot water systems in the building;
- lighting systems – for which a lighting design had been installed giving the design illuminance for each zone and the installed wattage;
- Solar thermal, photovoltaic panel, wind generators, and CHP were not installed and therefore were left blank.

Table 4-16: Ground Floor - Schedule of inputted building services data

Zone		Air Conditioning					Ventilation					Lighting			
Ref	Activity	Served by					System	Design air flow		Inst power	SFP	Lamp	Unit Power	Quantity	Total Inst Power
		System	Make	Model	SEER	SCOP		m³/hr	Pa	W	W/ l/s	Type	qty W	No	kW
Ground Floor															
Z0/01a	Waiting area	AC 7	Hitachi	Utopia G7 407C	2.49	2.88	SF 8	1500	100	650	1.17	Halogen spot	2 x 18	21	0.756
Z0/01b	Reception	AC 7	Hitachi	Utopia G7 407C	2.49	2.88	SF 8	1500	100	650	1.17	Halogen spot	2 x 18	10	0.36
Z0/02a	Meeting rooms	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	4	0.144
Z0/02b	Meeting rooms	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	4	0.144
Z0/02c	Meeting rooms	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	4	0.144
Z0/02d	Meeting rooms	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	4	0.144
Z0/02e	Meeting rooms	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	4	0.144
Z0/02f	Meeting rooms	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	4	0.144
Z0/02g	Meeting rooms	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	4	0.144
Z0/02h	Meeting rooms	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	4	0.144
Z0/02i	Meeting rooms	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	4	0.144
Z0/02j	Meeting rooms	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	4	0.144
Z0/02k	Corridors	HVAC 1	Hitachi	RSA24FSN	3.77	3.52	SF 8	1500	100	650	1.17	PL light	2 x 18	5	0.18
Z0/03	Board room	AC 1	Hitachi	Utopia G7 407C	2.49	2.88	SF 8	1500	100	650	1.17	PL light	2 x 18	10	0.36
Z0/04	Kitchen	AC 7	Hitachi	Utopia G7 407C	2.49	2.88	SF 1	500	75	165	0.89	Fluorescent T5	4 x 14	6	0.568
Z0/05	Communication rm	AC 5	Hitachi	Utopia G7 407C	2.49	2.88	SF 1	500	75	165	0.89	Fluorescent T5	2 x 35	9	0.63
Z0/06	Filing room	No air-conditioning					SF 1	500	75	165	0.89	Fluorescent T5	4 x 14	10	0.56
Z0/07a	Toilet	No air-conditioning					EF 1&2	2000	100	1300	1.76	PL light	2 x 18	6	0.216
Z0/07b	Toilet	No air-conditioning					EF 1&2	2000	100	1300	1.76	PL light	2 x 18	4	0.144
Z0/07c	Toilet	No air-conditioning					EF 1&2	2000	100	1300	1.76	PL light	2 x 18	2	0.072
Z0/08	Circ./lift area	No air-conditioning					Natural					PL light	2 x 18	4	0.144
Z0/09	Stores	No air-conditioning					Natural					Fluorescent T5	4 x 14	1	0.056
Z0/10	Electrical room	AC 2	Hitachi	Utopia G7 407C	2.49	2.88	Natural					Fluorescent T5	2 x 35	2	0.14
Z0/11	Manager's office	AC 8	Hitachi	Utopia G7 407C	2.49	2.88	SF 3	900	100	220	0.66	Fluorescent T5	4 x 14	5	0.28
Z0/12	Manager's office	AC 9	Hitachi	Utopia G7 407C	2.49	2.88	SF 3	900	100	220	0.66	Fluorescent T5	4 x 14	4	0.224
Z0/13	Open plan office	HVAC 4	Hitachi	RSA16FSN	3.24	3.12	SF 5	700	100	220	0.85	Fluorescent T5	4 x 14	48	2.688
Z0/14	Open plan office	HVAC 4	Hitachi	RSA16FSN	3.24	3.12	SF 2	900	100	220	0.66	Fluorescent T5	4 x 14	148	8.288
Z0/15	Toilets	No air-conditioning					SF 8	1500	100	650	1.17	PL light	2 x 18	1	0.036
Z0/16	Corridors	No air-conditioning					Natural					Fluorescent T5	4 x 14	4	0.224

4.3.3.3 *Rating*

Once all the geometry and building services data was input, the energy performance rating of the building was calculated using the rating tab. This rating gave a very conservative total annual energy consumption of 70.5kWh/m^2.yr, consisting of yearly consumption of 3.41kWh/m^2.yr for heating; 20.56 for cooling; 3.3 for auxiliaries; 28.05 for lighting and 5.18kWh/m^2.yr for domestic hot water, all as shown in Figure 4-7.

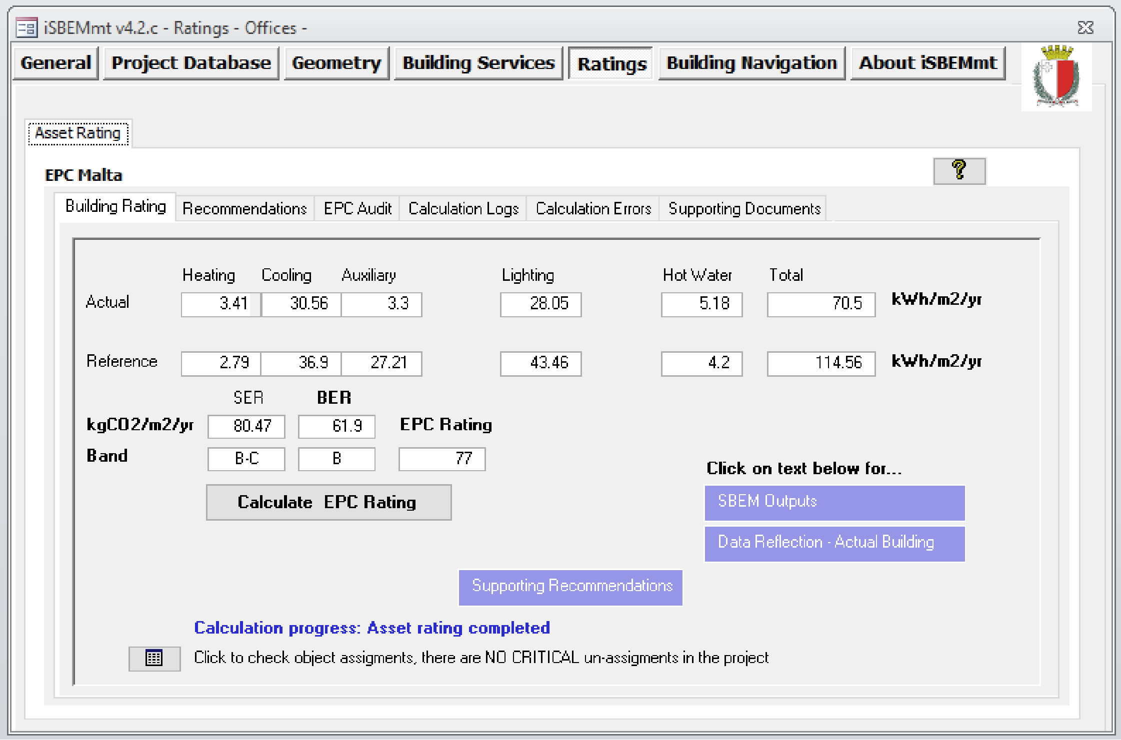


Figure 4-7: Unit annual energy consumption for each service

Figure 4-8 shows the outcome of the EPC, where sector-specific energy consumption is depicted, as well as the percentage contribution of the total energy consumption.

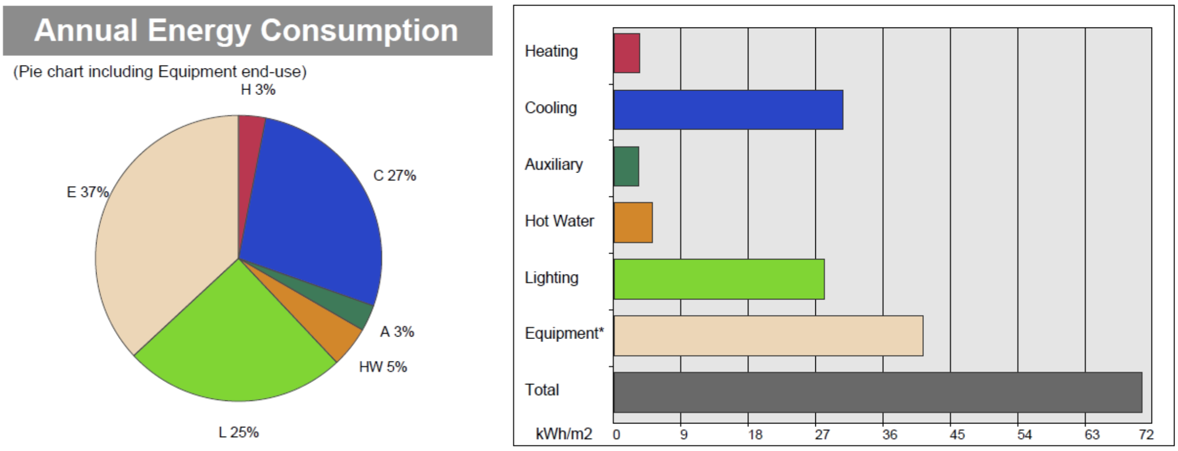


Figure 4-8: SBEM rating output

When projected to primary energy use, this rating reflected an EUI of 243.23 kWh/m².yr and an annual CO_2 emission of 61.9 kg/m² per year, which corresponds to an improvement over the standard reference building of around 15.6% less, thus attaining a grade B.

4.3.4 Actual measured energy consumption

Central electrical energy is taken from two main electrical panels installed inside the carpark at level -1, with separate metered electrical cubicles to:

- VRF outdoor heat pump units for each floor;
- Small power and lighting outlets to all floors;
- Ventilation of carpark;
- Lifts;
- Fire pumps.

Since SBEM-mt only deals with the energy consumed for cooling, heating, ventilation, domestic hot water services and lighting – in order to compare like with like, it is essential to extract the same information from the overall energy consumption. As regards the VRF outdoor units, this was continuously monitored, and it was possible to compile the data for the years 2011 through 2017, as shown in Table 4-17 below.

Table 4-17: Yearly metered energy consumption by the VRF outdoor units

Actual metered Energy Consumption — kWh per year

Year	2011	2012	2013	2014	2015	2016	2017
Ground Floor VRF outdoor units	73,853	79,316	76,262	73,622	87,274	91,741	88,492
First Floor VRF outdoor units	79,244	68,560	70,576	64,935	65,755	72,470	71,735
Total VRF outdoor measured	153,097	147,876	146,838	138,557	153,029	164,211	160,227

Energy absorbed by the other equipment, such as VRF indoor units, individual split units, fans and lighting had to be obtained by multiplying their operating power capacity with the daily operating hours.

In this case, the energy absorbed by the 105 VRF cassette indoor units each having a 70/60W motor, fed from 16 separate small power circuits, was calculated. These are operating for 9 hours per day and 6 hours on Saturdays on time-controlled schedule (2652 hours per year). The calculated consumption amounted to 16,708 kWh per year, as shown in Table 4-18 below. One has to assume that the nameplate power of selected motors is always around 20% higher than the absorbed power which makes up for the power factor together with the mechanical and electrical efficiencies losses.

Table 4-18: Energy consumption of the indoor units based on the duration of operation

AC Schedule — Operational Energy Consumption

Name		Working Hours			Max kWh per year
	Qty	Weekdays	Sat	Per Year	
HVAC System 1 (1/J)	12	9	6	2652	1,909
HVAC System 2 (1/I)	7	9	6	2652	1,114
HVAC System 3 (1/H)	7	9	6	2652	1,114
HVAC System 4 (1/G)	6	9	6	2652	955
HVAC System 5 (1/F)	6	9	6	2652	955
HVAC System 6 (1/E)	6	9	6	2652	955
HVAC System 7 (1/D)	6	9	6	2652	955
HVAC System 8 (2/A)	10	9	6	2652	1,591
HVAC System 9 (2/B)	6	9	6	2652	955
HVAC System 10 (2/C)	6	9	6	2652	955
HVAC System 11 (2/D)	8	9	6	2652	1,273
HVAC System 12 (2/E)	7	9	6	2652	1,114
HVAC System 13 (2/F)	6	9	6	2652	955
HVAC System 14 (2/G)	6	9	6	2652	955
HVAC System 15 (2/H)	3	9	6	2652	477
HVAC System 16 (2/I)	3	9	6	2652	477
Total	105.00	Total Indoor units			16,708

Similarly, each of the 9 individual split air-conditioners, i.e. AC 1 to AC9 had their annual energy consumption calculated by dividing their nominal cooling capacity of each unit by its COP to get the maximum absorbed power and then multiplied by the daily number of operating hours ,as per schedule and Table 4-19 below.

Table 4-19: Annual energy consumption of individual AC units based on the duration of operation

Name	Heating		Cooling		Qty	Working Hours				Max kWh per year	Applying an RMS value of 0.55 max
	Capacity kW	EER	Capacity kW	COP		Weekdays	Sat	Sun	Per Year		
AC1 (Board Room)	13.85	2.49	13.19	2.88	2	9	6		2652	12,145	6,680
AC2 (Elec. Room)	10.77	2.49	10.26	2.88	2	24	24	24	8736	31,116	17,114
AC3 (Elec. Room)	9.23	2.49	8.79	2.88	1	24	24	24	8736	26,671	14,669
AC4 (CEO office)	12.31	2.49	11.72	2.88	1	8	5		2340	9,525	5,239
AC5 (communication room)	10.77	2.49	10.26	2.88	2	24	24	24	8736	31,116	17,114
AC6 (Reception)	7.69	2.49	7.33	2.88	2	9	6		2652	6,747	3,711
AC7 Kitchen	7.69	2.49	7.33	2.88	1	9	6		2652	6,747	3,711
AC8 Manager's Office	10.77	2.49	10.26	2.88	1	9	6		2652	9,446	5,195
AC9 Manager's Office	10.77	2.49	10.26	2.88	1	9	6		2652	9,446	5,195
						Total				**142,957**	**78,627**

However, in this case and in view of the fact that energy absorbed by buildings in a place such as Malta, with massive solar radiation can be taken to vary daily, monthly and yearly quasi-sinusoidally [118], [118], a root mean square factor (RMS) of 0.55 of the maximum value was taken giving a more conservative energy consumption approach. This amounted to the total annual energy consumption of 78,627 kWh, as shown in Table 4-19 above.

Similarly, this was done for the ventilation supply and extract fans together with the domestic hot water boilers for which the annual energy consumption was calculated to be 19,829kWh and 10,464kWh, as shown in Table 4-20 and Table 4-21 respectively.

Table 4-20: Annual energy consumption of ventilation fans based on the annual operating hours

Supply Air										Operational Energy Consumption			
Ref	**Serving**		**Design air flow**		**Design ESP**	**Size**	**Inst power**	**Abs Power**	**SFP**	**Working Hours**			**kWh per year**
		Zone	**m³/hr**	**l/s**	**Pa**	**mm dia**	**W**	**W**	**W/ l/s**	**Week**	**Sat**	**Per year**	
Ground Floor													
SF1	Z0/	4, 5, 6	500.0	138.9	75.0	150.0	165.0	123.8	0.9	11	6	3172	393
SF2	Z0/	14	900.0	250.0	100.0	250.0	220.0	165.0	0.7	11	6	3172	523
SF3	Z0/	14	900.0	250.0	100.0	250.0	220.0	165.0	0.7	11	6	3172	523
SF4	Z0/	14	700.0	194.4	100.0	250.0	220.0	165.0	1.8	11	6	3172	523
SF5	Z0/	13	700.0	194.4	100.0	250.0	220.0	165.0	0.9	11	6	3172	523
SF6	Z0/	13	700.0	194.4	100.0	250.0	220.0	165.0	0.9	11	6	3172	523
SF7	Z0/	14	700.0	194.4	100.0	250.0	220.0	165.0	0.9	11	6	3172	523
SF8	Z0/	1a,1b,2a 2b,2c,2d,2e,2f,2g,2h,2i,2j,2k 3,15	1500.0	416.7	100.0	315.0	650.0	487.5	1.2	11	6	3172	1,546
First Floor													
SF9	Z1/	2, 3, 4, 5, 6, 7, 8, 9, 10	1500.0	416.7	125.0	315.0	650.0	487.5	1.2	11	6	3172	1,546
SF10	Z1/	14a, 14b, 14c	1000.0	277.8	100.0	315.0	650.0	487.5	1.8	11	6	3172	1,546
SF11	Z1/	11, 12, 13	950.0	263.9	125.0	315.0	650.0	487.5	1.9	11	6	3172	1,546
SF12	Z1/	16	350.0	97.2	100.0	150.0	165.0	123.8	1.3	11	6	3172	393
SF13	Z1/	16	700.0	194.4	100.0	250.0	220.0	165.0	0.9	11	6	3172	523
SF14	Z1/	16	350.0	97.2	100.0	150.0	165.0	123.8	1.3	11	6	3172	393
SF15	Z1/	17	750.0	208.3	100.0	250.0	220.0	165.0	0.8	11	6	3172	523
SF16	Z1/	24	700.0	194.4	100.0	250.0	220.0	165.0	0.9	11	6	3172	523
SF17	Z1/	23, 24	700.0	194.4	100.0	250.0	220.0	165.0	0.9	11	6	3172	523
SF18	Z1/	24	700.0	194.4	100.0	250.0	220.0	165.0	0.6	11	6	3172	523
SF19	Z1/	24	700.0	194.4	100.0	250.0	220.0	165.0	0.9	11	6	3172	523
TOTAL			**15000.0**	**4166.7**				**4301.3**		**Total**			**13,644**
Extract Air													
Ref	**Serving**		**Unit air flow**		**ESP**	**Model**	**Inst power**	**Abs Power**	**SFP**	**Working Hours**			**kWh per year**
		Zone	**m³/hr**	**l/s**	**Pa**		**W**	**W**	**W/ l/s**	**Week**	**Sat**	**Per year**	
Ground Floor													
EF 1	z0	7a, 7b, 7c	1000.0	277.8	75.0	315.0	650.0	487.5	1.8	11	6	3172	1,546
EF2	z0	6, 7a,7b,7c,	1000.0	277.8	100.0	315.0	650.0	487.5	1.8	11	6	3172	1,546
First Floor													
EF3	z1	14a, 14b, 14c	1000.0	277.8	75.0	315.0	650.0	487.5	1.8	11	6	3172	1,546
EF4	z1	6, 11, 12, 13	1200.0	333.3	100.0	315.0	650.0	487.5	0.9	11	6	3172	1,546
TOTAL			**4200.0**	**1166.7**				**1950.0**		**Total**			**6,185**
										Grand Total			**19,829**

Table 4-21: Annual energy consumption of hot water boilers based on a 2-hour recovery period

Ref	Installed in	Type	Capacity	Fuel	Recovery	Electrical load	Working Hours			kWh
	Zone		Litres		Hrs	kW	Weekdays	Sat	Per year	per year
HWS	Z0/05	Stand alone	20.00	Electricity	2.00	0.57	9	6	2652	1,520
HWS	Z0/08	Stand alone	50.00	Electricity	2.00	1.43	9	5	2600	3,726
HWS	Z1/10	Stand alone	50.00	Electricity	2.00	1.43	9	5	2600	3,726
HWS	Z|1/15	Stand alone	20.00	Electricity	2.00	0.57	9	5	2600	1,491
Total			**140.00**		**8.00**	**4.01**	**TOTAL**			**10,464**

Also, for lighting, the power of the installed lamps as given in Table 4-16 was calculated and multiplied by the number of hours in use, which included a half hour before and a half hour after at the end of work, thereby giving 9 hours per day on weekdays and 7 hours on Saturdays. This gave a total lighting energy consumption of 89,763 kWh per year.

For the unit annual energy consumption, these were all added up and divided by the total zones area. The mean of the seven yearly units was calculated to be 115.72 kWh/m² per year with a standard deviation of 2.71 kWh/m². Thus, the total unit energy consumption as actual on site was cycling between 111.5 to 118.32 kWh/m^2 per year, as shown in Table 4-22 below.

Table 4-22: Summary of actual and estimated energy consumption on site for respective services

Year	2011	2012	2013	2014	2015	2016	2017
Ground Floor VRF outdoor units	73,853	79,316	76,262	73,622	87,274	91,741	88,492
First Floor VRF outdoor units	79,244	68,560	70,576	64,935	65,755	72,470	71,735
Total VRF outdoor actual measured	153,097	147,876	146,838	138,557	153,029	164,211	160,227
Indoor VRF units	16,708	16,708	16,708	16,708	16,708	16,708	16,708
AC units split	78,627	78,627	78,627	78,627	78,627	78,627	78,627
Ventilation Fans	19,829	19,829	19,829	19,829	19,829	19,829	19,829
DHW	10,464	10,464	10,464	10,464	10,464	10,464	10,464
Lighting	89,763	89,763	89,763	89,763	89,763	89,763	89,763
Total actual estimated	215,390	215,390	215,390	215,390	215,390	215,390	215,390
Total actual measured & estimated kWh	**368,487**	**363,266**	**362,228**	**353,947**	**368,419**	**379,601**	**375,617**
Total Floor area m^2	3,175						
Total unit energy consumption	116.08	114.43	114.11	111.50	116.06	119.58	118.32
mean kWh/m^2 year	**115.72**						
Difference from mean squared	0.12	1.67	2.62	17.87	0.11	14.85	6.75
Total	7.33						
Standard deviation	**2.71**						
Min kWh/m^2 year	**113.02**						
Max kWh/m^2 year	**118.43**						

4.3.5 Performance gap analysis for Cluster type 2 building

The actual and estimated calculated readings were plotted and compared against the rating values as generated by SBEM-mt and are shown in Figure 4-9 below. From the graph, it is clear that during these last seven years for which the actual on-site consumption was somewhat steady and linear, there is a substantial mismatch between the energy consumption as predicted by SBEM-mt, to that actual and estimated. This amounts to almost 65% underestimated by SBEM-mt.

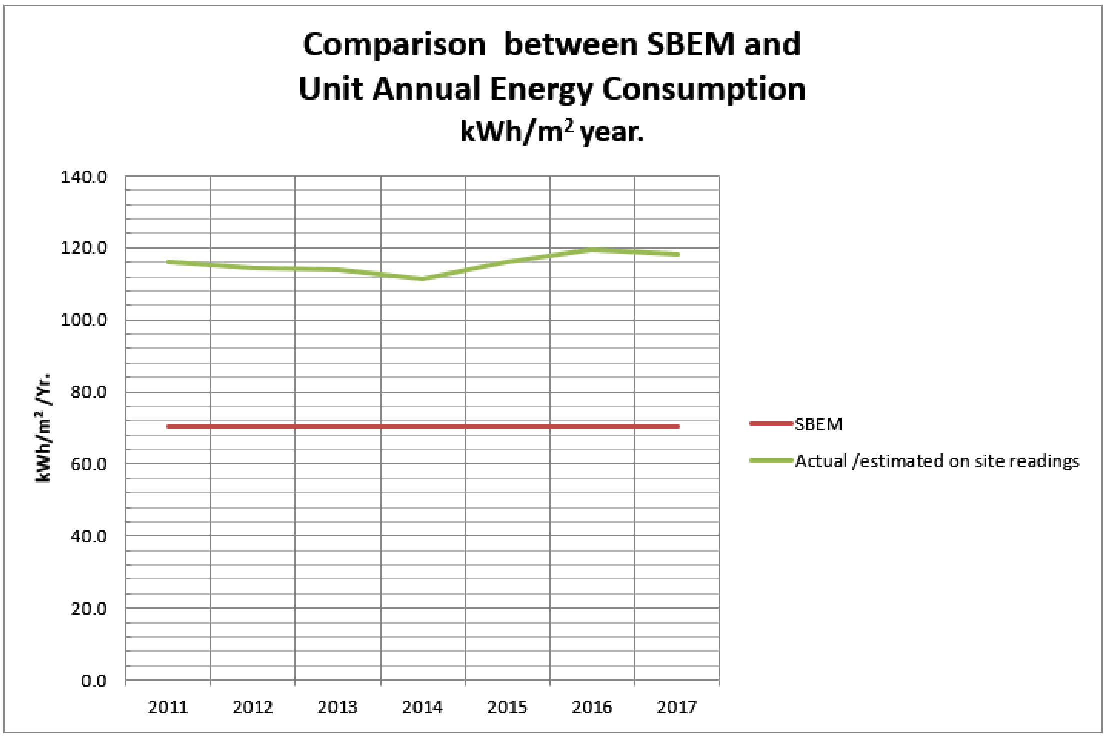


Figure 4-9: Graphical comparison of energy consumption as projected by SBEM to that measured

However, going through the individual systems loads, one can observe that the lighting load was very well on target. The most significant mismatch occurred in the HVAC systems, which was more than double that predicted, as shown in Table 4-23 below.

The mismatch is so significant that even when adding together SBEM yearly prediction for heating, cooling and auxiliaries (ventilation) at 37.72 kWh/m².yr, this could not even match the measured unit load of the VRF outdoor unit alone at 47.8 kWh/m², as shown in Table 4-22 above. Notwithstanding this, the complete HVAC system consists of other equipment besides outdoor VRFs, such as the energy consumed by the indoor units, individual split units, and ventilation fans.

Table 4-23: A system-by-system comparison of results as generated by SBEM to actual

Unit Annual Energy Consumption	**Average kWh/m^2 yr.**	
System	**SBEM-mt**	**Actual & estimated**
Heating	**3.41**	**77.91**
Cooling	**30.56**	
Auxiliary	**3.3**	**6.25**
Lighting	**28.05**	**28.28**
Hot water	**5.18**	**3.30**
Total	**70.5**	**115.72**

4.3.6 Discussion

In a predominantly cooling load country like Malta, this mismatch may all be related to the way cooling load is calculated, for which the SBEM uses the Admittance Method [127]. The Admittance Method tackles the problem of transient heat gains by assuming that they vary sinusoidally with a period of 24 hours and depending mainly on what is known as the Sol-Air temperatures on exposed surfaces, which then uses the principle of superposition to sum up the effects of individual heat gains. This procedure requires a lot of pre-determined complex data from actual buildings and results in the calculation of three other parameters in addition to the regular thermal transmittance (U-Value) such as the admittance, surface factors, and decrement factors [123]. These parameters depend upon the thickness, thermal mass, density and specific heat capacity of the materials used within the building structure and the relative positions of the various elements that make up a construction. Each of these parameters is expressed as amplitude and an associated time lead/lag in forming weighted factors.

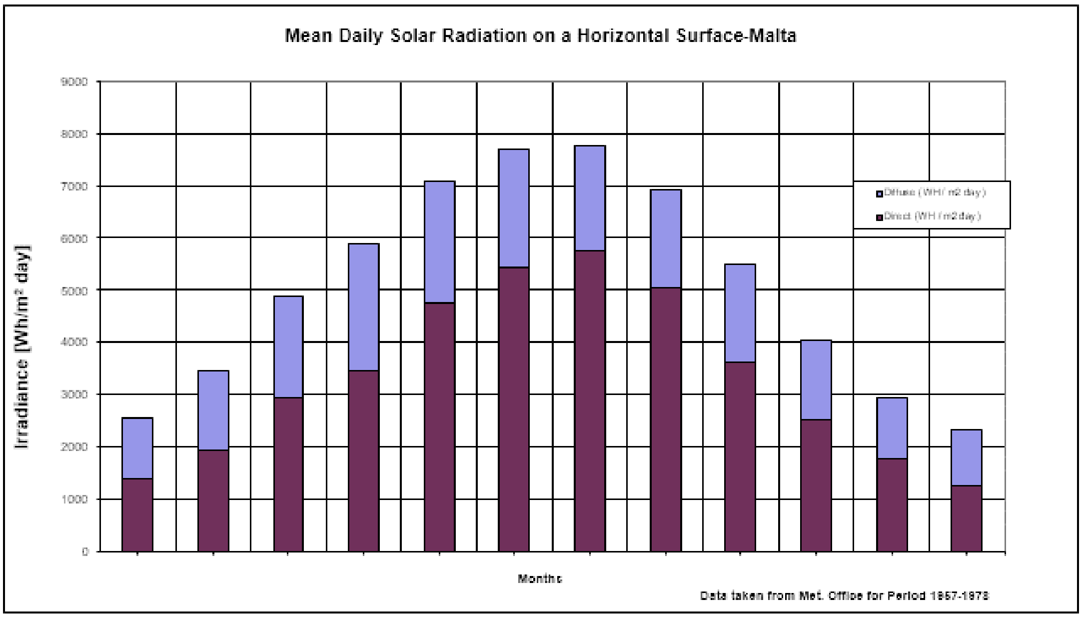
One needs to understand that a cooling load must consider heat gain into space from outdoors, as well as sensible and latent heat generated within the space. The variables affecting cooling load calculations are numerous, and the task of obtaining accurate estimates of cooling loads for commercial buildings is difficult and challenging. There are several reasons for this, mainly because:

- All three modes of heat transfer are involved in most thermal processes in buildings.
- A wide variety of materials are involved, with widely differing thermo-physical properties.
- The geometrical relationships between many building components are complicated.
- The factors which cause loads (solar radiation, outdoor temperature and humidity, and internal heat generation) all vary with time and are rarely in phase with one another.
- The heat storage capacities of most building materials are significant so that the thermal processes in a building are in transient rather than steady state.
- Given that this building was over-pressurised because there were no return fans installed, except the four extract fans in the toilets discharging outside, this may have substantially added to the cooling and heating loads since it is more than the normally allowed approximately 10%. However, because of SBEM raw methodology, this was not identified.
- Most of the heat transfer processes in a building are interrelated.

As for the Winter heating, the author who has professional experience of over 30 years in design, implementation and working in large modern open-plan offices which house large numbers of computers and peripherals, can confidently state that SBEM-mt may be over-rating the heating demand. This overheating was also observed during site visits, and through discussions with the operation and maintenance personnel, who confirmed that in Winter the air-conditioning systems are either switched off or put on an intermittent cooling mode. Otherwise, the personnel may have likely been at the receiving end of over-heating complaints from the employees.

In fact, when one calculates the number of HDD for the last 3 years, as reported by an internationally approved degree-day weather calculator such as BizEE software [108] for a standard base temperature of 15.5°C, Malta's average HDD per year is only 351. Comparatively, this is rather low when compared to other cities such as London, which has 2,500 HDD, or other European capitals, which can be much higher.

Notably, by taking the standard base temperature of 15.5 °C, this is rather high for Malta's climate, as the effect of daily solar gain is high and predominant. To this effect and given Malta's position on the globe, the direct and diffuse irradiation even in January reaches above 2,500Wh/m^2 on a horizontal surface, as shown in Figure 4-10 [118].



Mean Daily Solar Radiation on a Horizontal Surface (Watt- hours per m^2 per Day)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Diffuse (WH / m^2 day)	1177	1532	1943	2432	2340	2250	1990	1890	1875	1528	1183	1067
Direct (WH / m^2 day)	1390	1942	2926	3457	4753	5442	5771	5037	3631	2517	1765	1263
Global (WH / m^2 day)	2567	3474	4869	5889	7093	7692	7761	6927	5506	4045	2948	2330

Figure 4-10: Mean daily solar radiation on a horizontal surface[128]

When discerning from both theoretical and practical experience, it is wise to consider lowering the base temperature for such buildings to around 13°C, when the number of HDD will be substantially lower and will most likely occur outside the regular office hours (from around 8 am till 5 pm), as shown in red curve (noon) in Figure 4-11 below.

Additionally, given that seasons are well staggered locally, where a short period of heating may be needed in Winter, followed by an extensive mild Spring climate, and a hot and humid Summer, the use of mixed-mode types of operation for the air-conditioning system using one or more of the central supply air plants, should be considered. *Mixed mode* is a term used to describe servicing strategies that combine natural ventilation with mechanical ventilation and cooling/heating in the most effective manner. To date this approach has been used most widely in offices; however, it is suitable for a wide range of building types. CIBSE AM13: “Mixed mode ventilation” [129] addresses this problem by providing data based on real-life applications to give the broad level of knowledge required to make strategic decisions about mixed mode systems, and point out specific pitfalls.

This is so for those mild climate months for which the outside air is relatively much lower than the room temperature of 23.5°C as shown in Figure 4-11 and Figure 4-12 below [34]. In this mode, the indoor conditions could have been kept within the comfort zone by increasing the amount of filtered fresh air to maximum by an adiabatic controller of the psychometric process, thus eliminating the need to operate on cooling for most of the mild season’s months, such as Spring and Autumn.

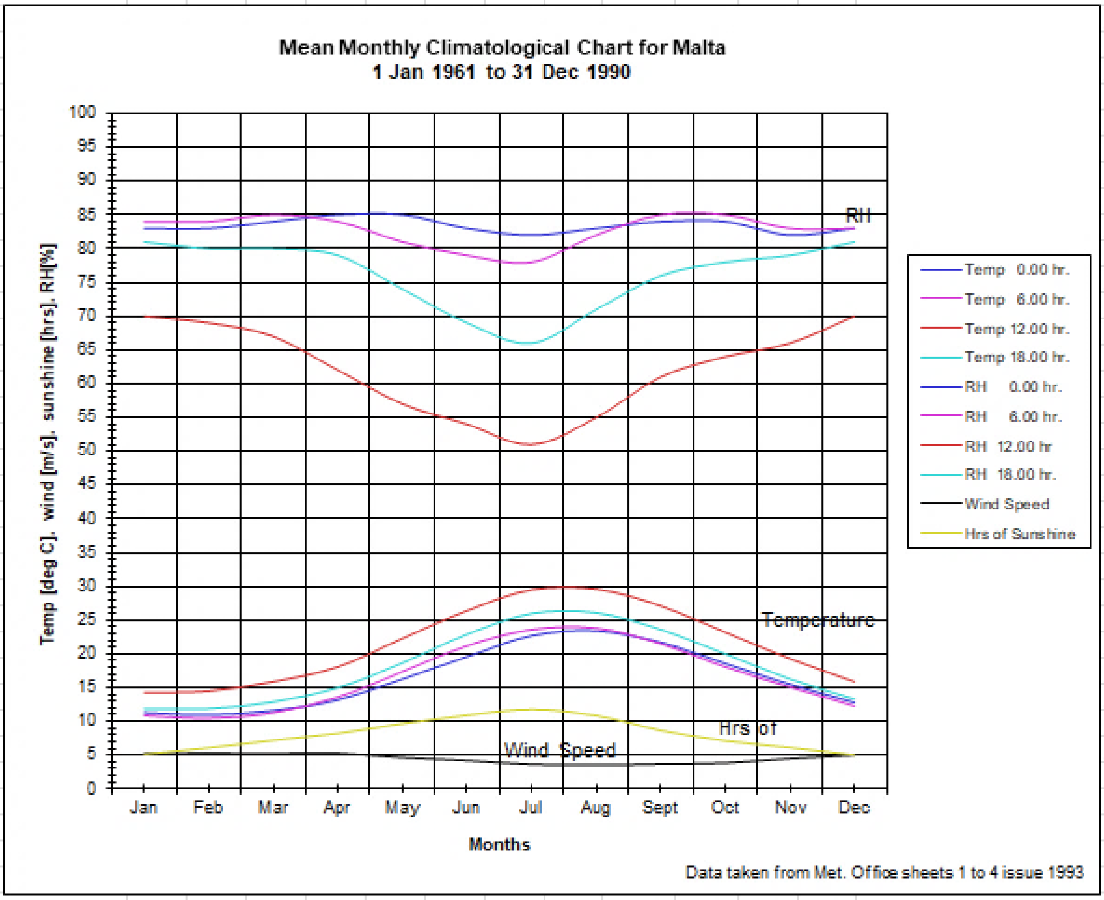


Figure 4-11: Air temperatures, RH and wind speed for Malta [118]

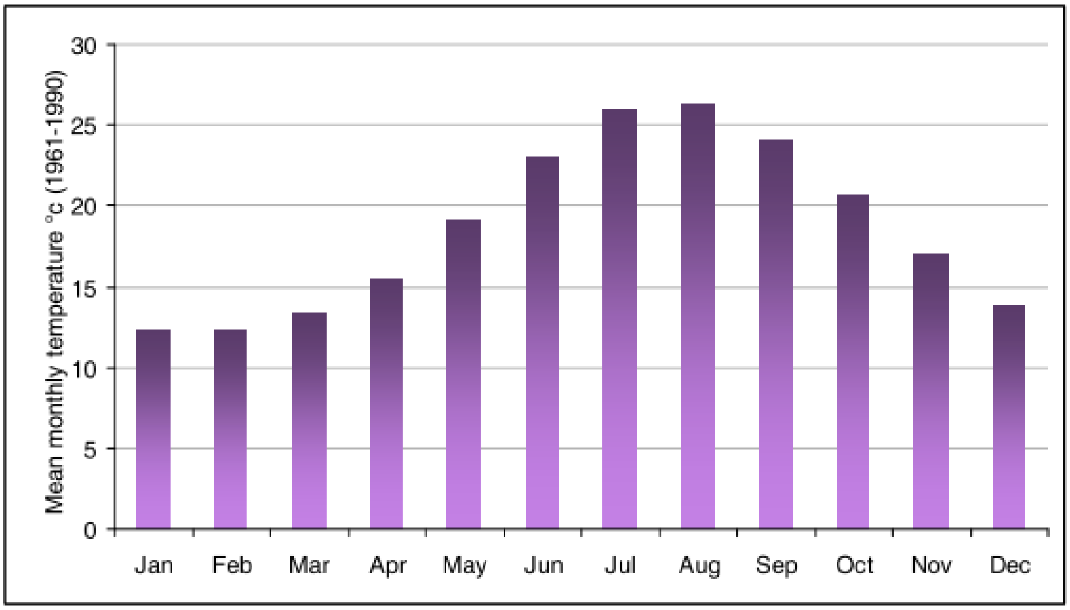


Figure 4-12: Mean monthly temperatures for Malta [118]

This mixed mode type of design and operation would not only consume less energy consumption due to free cooling; it would have also served as a:

a) Better containment of the refrigerant which can be harmful to the ozone depletion and global warming, because of the extended use of distribution refrigeration pipework used by the VRF systems running along the building and in which it is not easy to detect leaks.
b) Better quality since mixed mode units are factory manufactured, tested, packaged, and shipped as a complete assembly, with no refrigeration pipework to add expect for ducting to supply conditioned air.
c) Less operational noise because there are no indoor unit motors inside the premises, as all noise is within the air handling unit which is outside or in a plant room and can be controlled through sound attenuators.
d) Better coefficient of performance since the COP and EER of direct expansion VRF units, as given by the manufacturers, do not take into consideration losses due to the flow of refrigerant in the small-bore refrigeration pipework. Besides, one must add the power of the indoor units as well as the substantial pressure loss in the long distributing pipework to serve the indoor units, which together make substantial losses and depend heavily on the installation.

Finally, for this case study, the Specific Fan Power (SFP) is notable and is given by:

$$\mathbf{SFP} = \frac{(\,absorbed\ \ Power\ of\ supply\ + Return\ Fans)}{max\ \ airflow\ of\ either\ Fan} \quad (4\text{-}1)$$

In this project, no return fans were installed, so the calculated FSP was somewhat lower and better than the default value of SBEM-mt of 1.5W/l/s. Thus, SBEM-mt gave a better-projected yearly energy consumption of 70.09kWh/m^2 instead of 72.35kWh/m^2 as shown in Figure 4-13 below, when calculated with default values.

This is somewhat ambiguous because by not having return fans installed, as highlighted previously, besides making the building over pressurised, a large quantity of treated air, i.e. 15,000m^3/hr, was being lost to the outside through exfiltration, when doors or windows are opened or through the toilet fans.

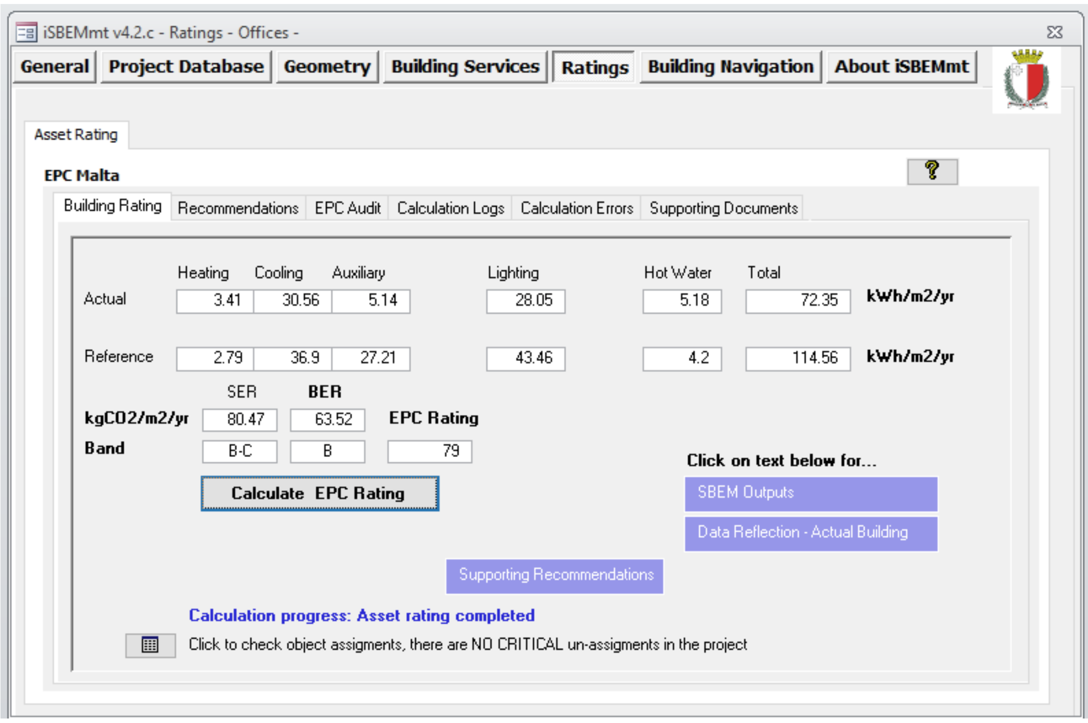


Figure 4-13: SBEM rating with the default specific fan power (SFP)

This overpressure will not only affect the comfort within the zones themselves and problems associated with door closures but will also eliminate the additional options to recover the energy from the air which is being discharged to outside as an energy saving opportunity.

4.4 Cluster type 3 Building – Mater Dei hospital building

4.4.1 The building

The Mater Dei hospital (MDH) is a 1,000-bed general and teaching hospital, which was completed and handed over in July 2007. It is unique for Malta, being so large and is the sole general hospital on the island, an island archipelago cut off from mainland Europe or Africa. The hospital's design philosophy had to be like an: "aircraft carrier in open seas" that is – whatever happens, it must go to the nearest port on its own steam. In such a case it had to be a smart build, and cater for:

a) Environmental friendliness – sustainable design for energy and water conservation; effective waste disposal; zero pollution;
b) Space utilisation and flexibility;
c) Value-giving quality for economic whole lifetime costs;
d) Human health and well-being;
e) Working efficiency and effectiveness;
f) Safety and security measures – fire, earthquake, disaster, and structural damages;
g) Culture, meeting client expectations;
h) Effective, innovative technology;
i) Construction and management processes; and
j) Health and sanitation.

To achieve all this, it was constructed on the basis of a Design and Build contract, a process that included:

- An international integrated design to UK NHS standards;
- Optimised energy efficiency brief;
- Optimised plant selection;
- Practical use of building management controls;
- Intricate handover; and
- Computerised Maintenance Management programmes (CMMS)

Figure 4-14: Aerial view of Mater Dei Hospital Complex

The hospital complex is built on ten levels from level 6 to level 15 with level 10 as the primary ground floor covering a useful area of nearly 250,000m^2 as shown in Table 4-24 and Figure 4-15 below.

Table 4-24: Mater Dei Hospital Built-up area in m² [130]

BUILT UP FLOOR AREA AS PER 15 Nov 2004 m²

BLOCK	A1	A2	A3	B	C	D	E	F	H	S3	S2	K1	CP	total area each level
Level 6													9767.82	9767.82
Level 7													9767.82	9767.82
Level 8				635	11537	17479.6	874.37	5142.86	337.2				16780	52786.1
Level 9	33.51	33.44	562.58	4679.74	12009.3	18017.3	4974.98	2715.31	1256.68	241.37	117.01	45.77	16780	61467
Level 10	2176.29	2175.73	613.9	2998.61	5409.39	12952.9	4413.36	2178.79	427.84				17240	50586.8
Level 11	2176.29	2175.73	444.8	2998.61	2406.77	11219.7	4413.36	697.4						26532.7
Level 12	323.21	361.33	395.34	2252.22	2455.45	10162.6	1826.6	612.38						18389.2
Level 13				2225.16	1853.11	9729.55								13807.8
Level 14					149.1	5833.79								5982.89
Level 15					499.17									499.17
Totals	4709.3	4746.23	2016.62	15789.3	36319.3	85395.5	16502.7	11346.7	2021.72	241.37	117.01	45.77	70335.6	249587

The hospital consists of the following blocks, listed below.

- **Block A** – General Administration Blocks including: Institute of Health Care, and Auditorium covering: Blocks A1, A2, and A3.
- **Block B** – Renal & Pathology including Physiotherapy, Occupational and Speech therapy, covering: Blocks B1 and B2.
- **Block C** – General Medical and Patient Services including Main entrance, Staff and visitors' canteen and Chapel, covering: Blocks C1 and C2.
- **Block D** – Accident and Emergency, Ward areas, Operating theatres ITU, CITU, covering: Blocks D1, D2, D3, and D4.
- **Block E** – Outpatients Department. and Specialised Clinics, covering: Blocks E1 and E2.
- **Block F** – Utility Block including: Boilers, Chillers, Hot Water services and Generators.
- **Block H** – Mortuary.
- **Block P** – Car Parks.
- **Block T** – Mains water, fire and treatment tanks

Figure 4-15: Mater Dei Hospital Ground Floor (level 10) [130]

Though excluded from the EPC certificate in 2015/16, a new block, the Medical Assessment Unit, was added inside the open space next to the Emergency Department with all services fed from the same existing plant rooms. Later on, a new independent hospital (except for the main 11KV power supply) for a 108-bed Oncology Centre was built on the east side of the main entrance. This centre is interconnected to the MDH through a high-level bridge, ring road, and underground tunnels as shown in Figure 4-16.

Figure 4-16: The new Oncology Centre at level 10 with an interconnecting bridge to MDH

4.4.2 The architectural design

The hospital was built on a local village concept inspired by Maltese architecture having its place of worship as its central point surrounded by distinct departmental blocks interconnected horizontally at ground and below ground levels through long circulation corridors for more easy access and interconnected with 52 large passenger or bed lifts for vertical transport. These corridors also serve as a quick means of escape through a horizontal progressive evacuation in case of fire. The hospital is unique on the island, and in case of a calamity, it has to withstand until assistance is provided from abroad.

At the time of design and build in 2000, the local Technical Document F [131] was not yet in place. As part of the 2006 legislation [52], the architects and designers saw it fit to build with passive design principles and incorporate sustainable conservative environmental concepts and materials. All windows are small, fitted with movable blinds inside sealed double pane clear glass and controlled from the rooms. They are relieved back and inclined to make use of natural lighting yet at the same time with reduced thermal loading due to the shadows cast by the lintel overhangs in substantial number of months when the sun is high, as shown in Figure 3-1 and Table 4-25 [119] below.

Table 4-25: Different Sun's altitude angles at noon in the Northern hemisphere during the months [119]

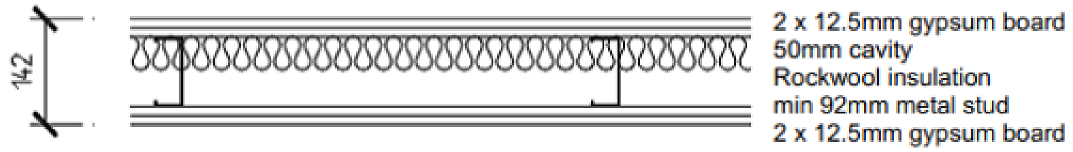
LATITUDE [North]	Mid January	Mid February	Mid March	Mid April	Mid May	Mid June	Mid July	Mid August	Mid Septembe r	Mid October	Mid November	Mid December
60	10	16	26	40	49	53	51	44	33	21	12	8
55	14	22	31	45	54	58	56	49	38	26	18	12
50	19	27	36	50	59	63	61	54	43	31	22	17
40	29	37	47	60	69	74	71	64	53	41	32	27
35	34.5	42	51.5	65	74	78.5	76	69	58	46	37	32
30	40	47	56	70	79	83	81	74	63	51	42	37
20	49	58	66	80	89	87	89	84	72	61	52	47
10	59	67	76	90	81	77	79	86	83	71	62	57
0	69	77	87	80	71	67	68	76	86	81	72	67

It is built on a superstructure concrete concept with flat floors and ceilings resting on columns and beams with light double 20mm thick 100mm insulated gypsum partitioning, and massively constructed external traditional natural light-coloured globigerina limestone composite wall made up from external inwards-facing:

- 150mm thick stone masonry block pointed and self-finished
- 30mm air cavity
- 50mm thick Rockwool insulation
- 230mm thick concrete shear wall
- 10mm thick gypsum plaster.

Thus, having its overall coefficient of heat transmission (U Value) of not more than 0.57 W/m^{2}K. The overall composite U-values for external walls with symmetrical windows, glazing frame, lintels, etc. is given in Figure 4-17 below.

Uniquely, the use of metal ties in double skin masonry walls eliminated the use of masonry header bond stones to tie both skins to function as a double wall without additional loss of heat transfer across the bond stones. Moreover, the lack of any physical barriers within the masonry wall cavity allows the introduction of an insulation layer tied with appropriate stainless-steel stays to the dry inner skin and allows an interrupted air cavity between the outer skin and the insulation layer within the cavity, as shown in Figure 4-18 below.



Wall type W1e

Fire resistance: -
Sound reduction: R'w 52dB
Other requirements: -

TYPICAL INTERNAL PATIENT ROOM NON-LOAD BEARING GYPSUM WALL

Wall Type	U north	U north (wet)	U south	U south (wet)
1.1.1	0.471	0.482	0.461	0.471
1.1.2	0.473	0.490	0.463	0.479
1.1.3	1.639	1.869	1.522	1.718
1.1.4	2.624	3.448	2.337	2.967
1.1.5	1.967	2.309	1.801	2.083
1.1.6	1.818	1.818	1.675	1.675
1.1.7	2.398	2.398	2.155	2.155
1.1.8	0.399	0.399	0.392	0.392

EXTERNAL WALLS “U” VALUES

Figure 4-17:Typical internal and external fabric and their respective composite U values [130]

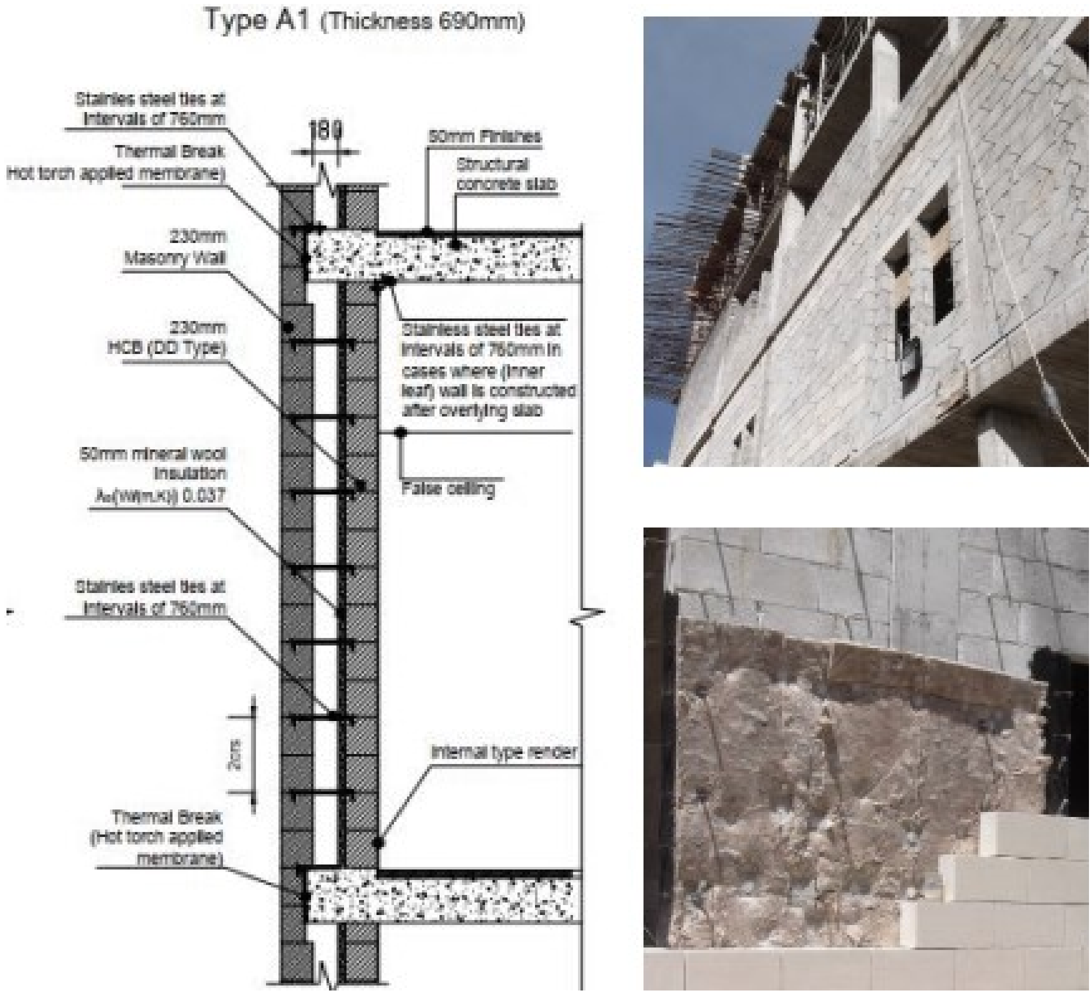


Figure 4-18: Details of double external walls with metal ties instead of bond stones [130]

Roof, ceilings, and floor are made up of *predalles* supported on flush beams thereby achieving a flat structural slab with no protruding structural elements. To determine the thermal transmittance of the roof, its mean value over a representative area must be determined. Therefore, the *predalles* section may be considered as solid concrete in three parts, i.e. the edges and the central one, with a 250mm thick high-density polystyrene insulation sandwiched in between the other two parts as shown in Figure 4-19.

For floors and ceilings, this gives an overall U-value 0.279 W/m^2 K, while for the roof an additional 60mm thick high-density insulation slab was inserted on top and below the screed to sustain the same U-value.

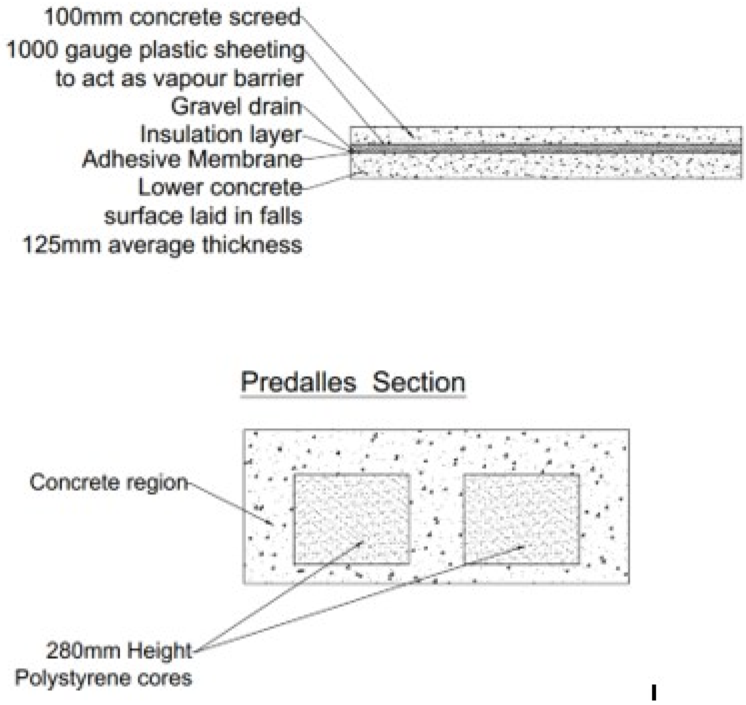


Figure 4-19: Cross section of “Predalles” and additional 60mm insulation + membrane on the roof [130]

4.4.3 The engineering Design

All the building services engineering systems were designed and built by reputable international firms following CIBSE, ASHRAE, and other approved international medical standards and guidelines [115], [132]–[134] [135].

4.4.3.1 MDH HVAC and DHW systems

With a closed window policy, the HVAC system of this hospital is generally a complex constant volume, single pass throwaway type, all year-round air-conditioning. Thus, the primary air-handling units treat the required quantity of fresh air for sanitation and at the same time ensure that the air is dry enough so that condensation does not occur while being supplied to the wards, in order to control the spread of *Legionella* bacteria. On the other hand, a secondary hydronic system with water working temperatures above the dew point of air, takes up the rooms' sensible loads through chilled beams (CB) or fan coil units (FCUs). Individual room controls are through wall-mounted wired controllers.

In areas where the growth of *Legionella* bacteria is considered critical such as in patients' wards and treatment rooms, passive type C are used, where the cooling medium is water at a temperature above the dew point of the air. Thus, no condensation is possible. Chilled beams are of the passive type thus have no fans or motors and suck return air just by a venturi, applying Bernoulli's principle. Hence, not only no condensation is present, but these chilled beams are economical to run with no absorbed power and silent, as schematically shown in Figure 4-20.

In Block D alone, there are more than 100 double or triple-decker air handling units (AHUs) in 12 plant rooms serving:

- 24 operating theatres;
- the recovery area;
- 12-bed intensive therapy units;
- a cardiac critical care unit
- catheterisation suites; and
- surgical and treatment wards.

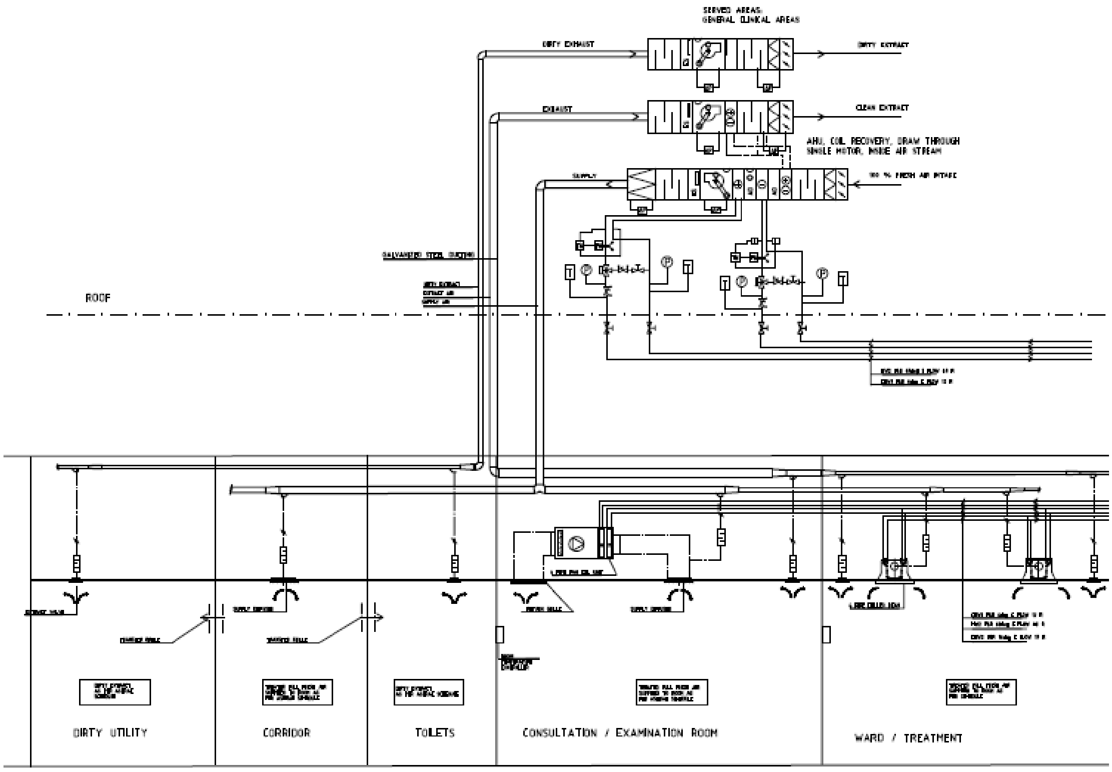


Figure 4-20: Typical schematic layout of the HVAC system at MDH

Psychrometrically, going through this as shown in Figure 4-21, room air return i.e. Point (2) is sensibly cooled before moisture can be condensed to Point (5) (i.e. to 100% saturation line) by chilled water inside the CBs above the dew point of air i.e. using water at 16℃ water flow and 19℃ return. After which this air is mixed with the cooled treated outside air through AHU to air Point (4), which is then supplied to the rooms at Point (S) to absorb the room load along the room ratio line (RRL).

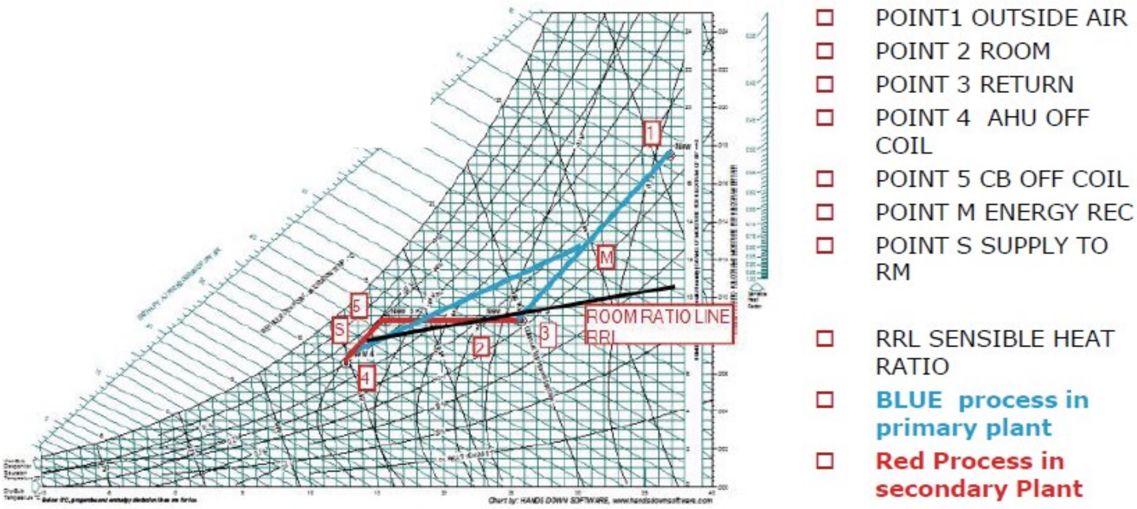


Figure 4-21: Typical cooling psychrometric process using chilled beams with no drip trays or condensate.

Around 65% of the energy inside the treated fresh air is partly recovered through heat exchangers inside the Ahau’s between the supply and extract points. In areas where the risk of contamination could be hazardous such as wards and treatment rooms, run-around coils are used. While in other less risky spaces, such as offices, thermal recovery wheels are used since they are more efficient, however requiring a substantial additional investment. Nevertheless, this made the HVAC and water systems of Mater Dei alone very complicated with the following arsenal of equipment, some of which is illustrated in Figure 4-22:

- 2 water-cooled chillers of 1200kW each for DHW pre-heating and provision with dry coolers when recovery is not in use;
- 14 packaged air-cooled chillers of 1200kW each;
- 4 fuel oil boilers of 2000kW each;
- 120 Fresh Air AHUs with supply and extract insulated galvanised steel ducting;
- 310 duplex chilled and heating pumps;
- 110 heat recovery pumps;

- 99 cooling and heating duct coils;
- 370 2-pipe cooling fan coil units;
- 1025 4-pipe cooling and heating fan coil units;
- 1773 active chilled beams with heating coils;
- 65 panel radiators;
- 85 fans;
- 55 split unit air-conditioners;
- 1 main electrical cable supply 33kV/11kV 22.5MVA transformer;
- 5 electrical substations 11kV/400V;
- 20, 1.6 ~ 3.2MVA resin cast air-cooled transformers 11kV/400V.

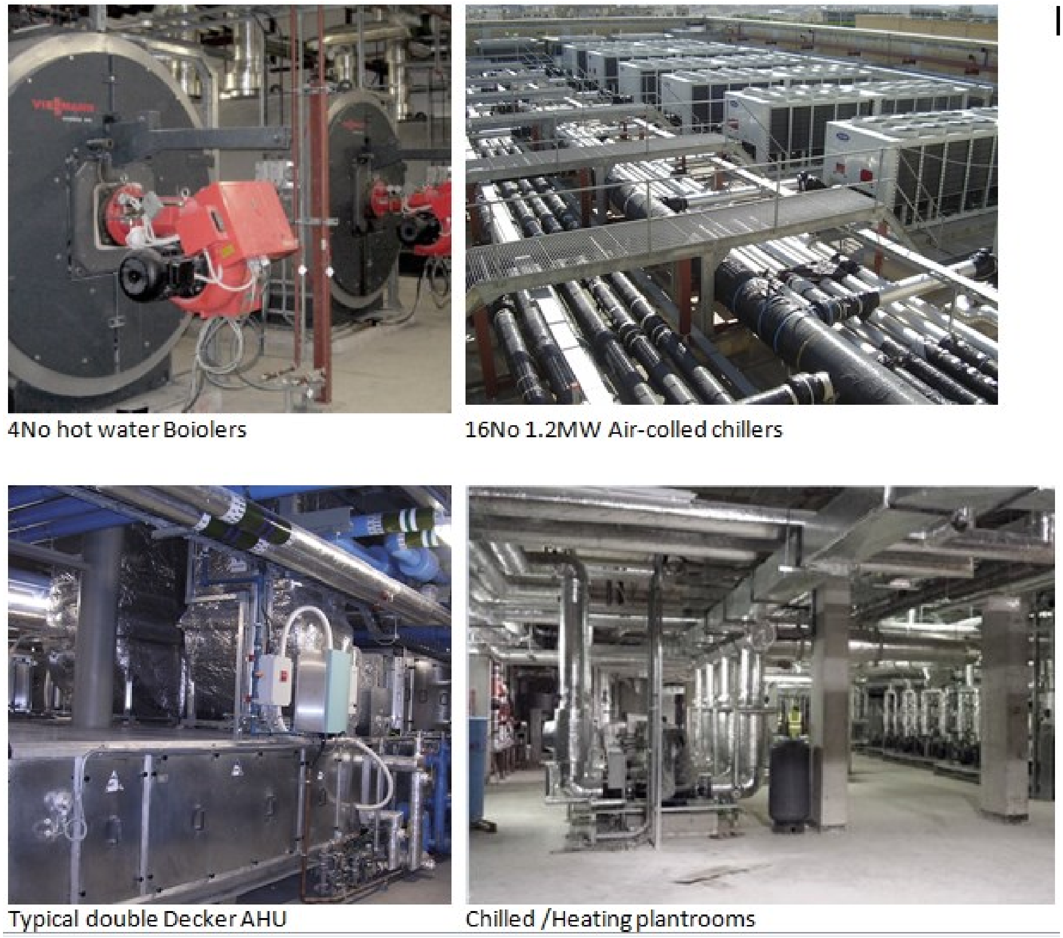


Figure 4-22: Typical photos of installed equipment [130]

4.4.3.2 Mater Dei Hospital lighting design

The lighting engineering design was based on CIBSE LG2 – *Lighting guide for hospital and healthcare buildings* [135], [134] and the appropriate UK NHS Design and build digital services documentation [136].

In the early 2000s, at the time of the initial lighting design, T5 lamps or LEDs had not entered the lighting market, as a cost-effective energy efficient alternative to traditional light sources such as incandescent and T8 fluorescent bulbs.

Thus, to achieve the lighting levels, more than 30,000 luminaries split into five categories from A to E, as partly shown in Table 4-26 below, were selected and installed all over the hospital, namely:

a) A1 to A66 ceiling mounted luminaries

b) B1 to B32 wall mounted luminaries

c) E-XA to E-XD external lamps

d) X-P1 to XW1 planter lamps

e) D1 to D2 floor mounted lamps.

Table 4-26: Part lighting specification showing type of luminaries

CODE	LUMINAIRE	LAMP & BALLAST	APPLICATION	DESIGN REFERENCE
A1	Recessed Circular Night light (IP20)	PL-C/2P, 4000K 1x10W, HF	Patient room	N.A.
A2	Recessed Circular (IP20)	PL-T/4P, 4000K 1x26W, HF	WC, Store, Clean	Marlin (Lexis Range) LXH126TPG3HF Or equivalent.
A3	Recessed Circular Protective cover (IP44)	PL-T/4P, 4000K 1x32W, HF (opt. emergency)	WC/Sh. ass. WC/Bath ass., Bath ass., WC ass., Shower	Marlin (Lexis Range) LXH132TPG3HF Or equivalent.
A4	Recessed Linear Down/up Light (IP 20)	'TL'D, 4000K 1x36W, HF (opt. emergency)	Corridor	Zumtobel (RCE) 1/36W EVG M600 Or equivalent
A4D	Recessed Linear Down/up Light (IP 20)	'TL'D, 4000K 1x36W, Dimm.	Corridor	Zumtobel (RCE) 1/36W EVG M600 Or equivalent
A5	Recessed Linear Modular ceiling (IP20)	'TL'D, 4000K 2x36W, HF (opt. emergency)	Treatment, Admission, Neonatal resurrection.	Thorn (Spec-Line) FTBZ236+FTP612FR or equivalent.

4.4.3.3 Controls

All the engineering services, fire dampers, fire pressurization, electrical load shedding during power outages, various alarms from systems such as medical gasses, lifts, tanks, laundry chute system etc. are controlled from a 60,000-point BMS. This BMS controls, monitors and supervises through 73 panels fitted with a ring network and graphics and human-machine interfaces, as shown in Figure 4-23 below:

- 970 temperature sensors
- 920 pressure sensors and switches
- 99 humidity sensors
- 605 control valves
- 435 air damper actuators
- 1000 motor starters, 210 of which are variable speed drives (VSDs)

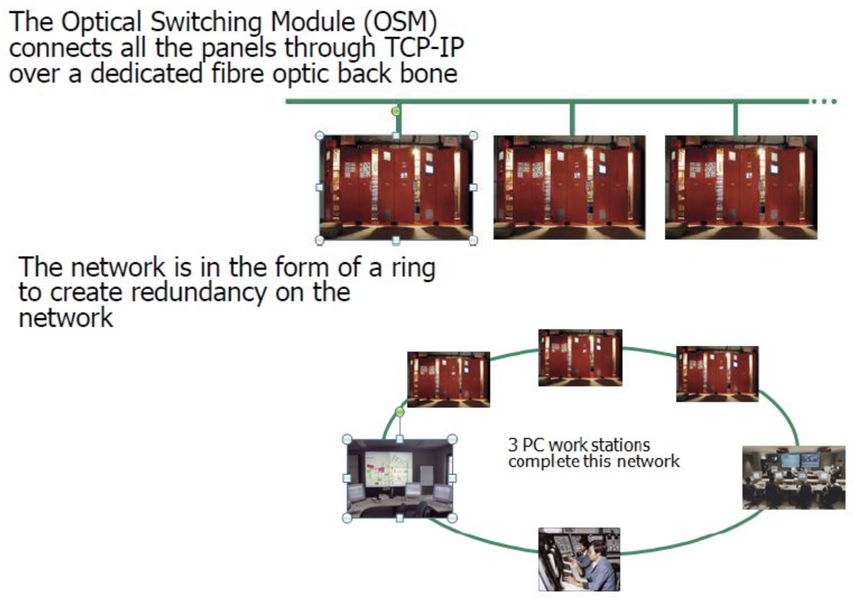


Figure 4-23: BMS architecture topology[130]

Thus monitoring:

a) scheduled stopping and starting;

b) environmental conditions, systems, and plants;

c) centralised alarms reporting;

d) reducing energy use and cost through centralised control of energy consuming systems for better sustainability;

e) data trending;

f) load shedding; and

g) provision of historical records.

4.4.4 SBEM input data, energy consumption and CO_2 emittance rating

In 2015, a contract was given to a local firm having a team of registered SBEM assessors on non-dwellings to issue an Energy Performance Certificate in line with the local legal notice and BRO methodology.

From a sample that was used from the building, the assessor produced a certificate for the Mater Dei Hospital as having an annual Primary Energy Consumption of 1375kWh/m^2.yr and a CO_2 emission of 351kg/m^2.yr, as shown in Figure 4-24.

BUILDING REGULATION OFFICE

ENERGY PERFORMANCE CERTIFICATE OF BUILDINGS MALTA

Certificate Reference Number:
N 0011 00016 2505 / 2015

Registration Date: 25 May 2015

Registered by the Building Regulation Office in accordance with Legal Notice 376 of 2012

Rating Type:	Asset
Building Type:	Residential Institutions - Hospitals and Care Homes
Useful Floor Area:	1498 m^2

Building Primary Energy Use: 1375kWh/m^2.yr

Building CO_2 Emissions: 351 kg/m^2.yr

Less CO_2 emissions

A+ .... Net zero CO_2 emissions

A 0-50

B 51-100

C 101-150

D 151-200

E 201-250 ◀ 229 EPC rating for this building

F 251-300

G over 300

More CO_2 emissions

Assessor Details	**Expiry Date of Certificate**
Name:	25 May 2025
Registration No:	This certificate is valid for a maximum period of 10 years from the date of registration provided there are no construction, fittings, or equipment changes in the building during this period.
Signature and Stamp:	

Page 1 of 2

This Energy Performance Certificate was produced by assessment software SBEMmt v4.2.c using calculation engine SBEMmt v4.2.c.0

Figure 4-24: MDH Energy Performance Certificate – Page 1

From the certificate and as shown in Figure 4-25, it is evident that a sample of an area was taken at level 10 (Ground Floor) of Block D1, which is mainly medical wards next to the emergency department.

Building Details and Façade

Property Address:
Mater Dei Hospital Block D1
Tal-Qroqq

Locality:
MSIDA (L-Imsida)

MEPA Application Number:
Not applicable

Year of Major Renovation (where applicable):
Not applicable

Site Plan

Centre co-ordinates of property: 52811 Easting 73444 Northing

This Energy Performance Certificate is valid ONLY if accompanied by a *Calculation Output Document* and a *Recommendations Report* for the building.

Additional information about the main building characteristics may be viewed on the website of the Building Regulation Office, by inputting the *Certificate Reference Number* in the *EPC Validity Check* box.

Page 2 of 2

This Energy Performance Certificate was produced by assessment software [illegible] using calculation engine [illegible]

Figure 4-25: MDH Energy Performance Certificate – Page 2

This energy consumption and the CO_2 emissions, were generated from an annual 440kWh/m^2 made up of systems as shown in Table 4-27 and Figure 4-26, respectively.

Table 4-27: SBEM projection on annual energy consumed per system

System	Percentage	kWh/m^2.yr
heating	1%	4
cooling	36%	158
auxiliary	40%	176
hot water	13%	57
lighting	10%	44
total	**100%**	**440**

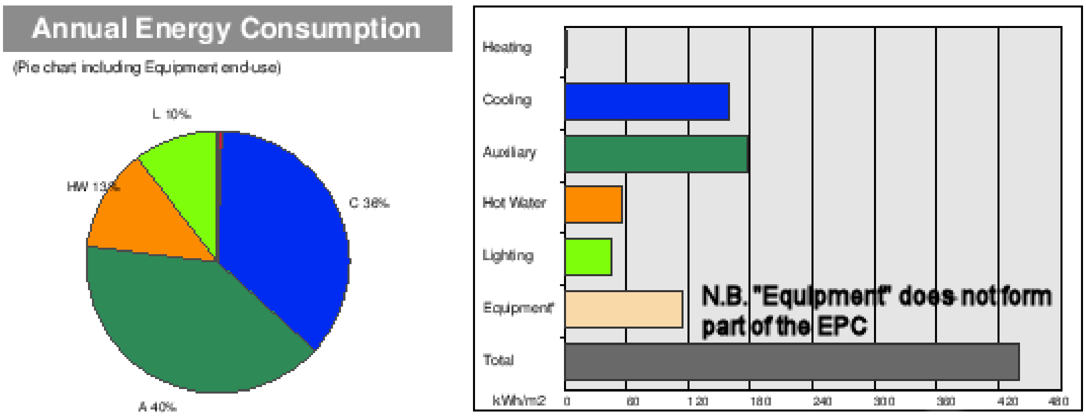


Figure 4-26: Annual system energy use intensities for MDH

4.4.5 Actual energy Consumption

Monthly electric utility bills were used to calculate the actual exact electrical energy and fuel consumed during years 2014 to 2016, which as shown in Table 4-28 below, the electricity consumption alone is nearly one million kWh per week.

Table 4-28: Quantity of fuel and Electricity used during 2014 to 2016

Year	2014	2015	2016	Units
Floor area	249,587	249,587	274,611	m²
Electricity consumed	41,155,200	47,389,533	55,445,900	kWh
Qty of fuel used	1,177,800	1,536,900	1,799,584	Litres

One must note that the values given for 2014 and 2015 include the power to build the New Oncology Centre and the Medical Assessment Unit, which were commissioned in 2016 and thus increased the floor area by around 10%.

So, taking 2015 as the base year for the electrical energy consumed, i.e., the year when the EPC was carried out, one can calculate the primary energy by multiplying the delivered electrical energy 47,389,533 kWh by the PEF of 3.45, which is the factor used in SBEM-mt software (see Table 4-29), to more than 163 million kWh, as shown in Table 4-30 below.

Table 4-29: primary Energy conversion factors for Malta [137]

Fuel	Primary energy factor	CO_2 emission factor
		[kg/kWh]
LPG (propane or butane)	1.1	0.232
Heating oil	1.1	0.272
Diesel	1.1	0.298
Kerosene	1.1	0.293
Biodiesel	1.2	0.050
Electricity	3.45	0.878
Wood	1.1	0.025

Similarly, it is possible to obtain the primary energy of the gas oil fuel, by multiplying the number of litres used by the fuel density and the calorific value and allowing an additional 10% for production and transportation (primary energy factor from Table 4-29) [137], which in turn yields more than 17 million kWh, as shown in Table 4-30.

Table B - Heating Gas Oil (HGO)

Property	Value - Range	Test Method (ASTM) *1
Density @ 15 °C	0.860 max	D 1298
Cetane Index	45 min	D 976
Sulphur content %	0.1% max	D 129
Flash point	55 min	D 53
Pour point	-10 °C max	D 97
Colour	1.5 max	D 1500
Ashes (m/m)	0.01%	D 482
Distillation Initial Boiling Pt At 250 °C At 350 °C Final Boiling Pt	 170 °C min 65% max 85% min 370 °C max	D 86
Water and Sediment (v/v)	0.5% max	D 2709
Viscosity @ 40 °C	2.0 - 4.5 cSt	EN ISO 3104
Carbon Residue (m/m)	0.15% max	D 524
Filterable dirt (mg/100ml)	4 max	D 2276
Sodium ppm	0.5 max	D 3605
Potassium ppm	0.5 max	D3605
Lead ppm	0.5 max	D 3605
Calcium ppm	2 max	D 3605
Vanadium ppm	0.5 max	D 5863/A
Hydrogen (m/m)	12% min	D 5291
Carbon Content %(m/m)	to be reported	D 5291
Gross Calorific Value kcal/kg	10 300 min	D 240
Net Calorific Value kcal/kg	to be reported	
CFPP	0 °C max	IP 309

Figure 4-27: Characteristics of type D gasoil fuel taken from the issued tender documents

Consequently, when the primary energy of both electricity and fuel were added together and divided by the total hospital area, the annual primary EUI was found to be 725 kWh/m^2, as shown in Table 4-30 below.

Table 4-30: Unit Primary Energy Consumption for 2015

Primary Energy Consumptions		
Year	2015	
Electricity consumed	47,389,533	kWh
Grid factor (source BRO)	3.45	
Primary electrical energy consumed	163,493,889	kWh
Fuels consumed	15,824,093	kWh
Primary energy factor for production and transport	1.1	
Fuel primary energy consumed	17,406,502	kWh
Total primary energy consumed	180,900,391	kWh
Primary EUI	**725**	**kWh/m².yr**

Also, when the delivered electrical and heating oil energy consumption were multiplied by the 2015 carbon emission factors (CEF) of 0.878 and 0.272 [137] respectively, it resulted in a yearly CO_2 emission of 186kg/m^2, as shown in Table 4-31 below.

As such, as summarised in Table 4-31, these actual unit loadings of energy consumption and carbon dioxide emission are much lower than those predicted by SBEM-mt at 1375kWh/m^2.yr and 356kg/m^2 respectively,. Clearly, the results of SBEM-mt indicate a pessimistic performance gap between predicted and as measured energy use.

Table 4-31: Unit CO_2 emissions for 2015

CO_2 Emissions		
Electricity consumed	47,389,533	kWh
Kg of conversion factor CO2 per kWh	0.878	kg/kWh
total CO2 produced	41,608,010	kg
Unit CO2 per m²	167	kg/m²
Fuel Consumed	17,406,502	kWh
Kg of conversion factor CO2 per kWh	0.272	kg/kWh
Total CO2 produced	4,734,569	kg
Unit CO2 per m²	19	kg/m²
Total CO_2 produced	**186**	**kg/m²**

An analysis was done for the three-year period from 2014 to 2016, and the mean was found to be around 181kg of CO_2 /m^2 varying along the years from 159 to 197 kg/m^2, as shown in Table 4-32 below.

Table 4-32:Summary of actual annual CO_2 discharge from 2014 to 2016

Year	**2014**	**2015**	**2016**	**units**
Floor area	249,587	249,587	274,611	m^2
Electricity Consumed	41,155,200	47,389,533	55,445,900	kWh
Qty of fuel used	1,177,800	1,536,900	1,799,584	Litres
Actual total primary energy used	155,324,876	180,900,391	211,669,943	kWh
Unit actual primary energy used	622	725	771	kWh/m^2.yr
SBEM	1,375	1,375	1,375	kWh/m^2.yr
Unit CO_2 produced due to primary electricity	145	167	177	kg/m^2.yr
Unit CO_2 produced due to primary fuel	15	19	20	kg/m^2.yr
Total CO_2 produced per unit area (EPC certificate)	**159**	**186**	**197**	**kg/m^2.yr**
Percentage rise from 2014		17%	24%	
Mean		181		kg/m^2.yr
Standard deviation	Min	166		kg/m^2.yr
	Max	198		kg/m^2.yr

NOTES

In 2016 floor area increased due to the opening of the Oncology centre and MAU.

This means that SBEM-mt overestimated the rating by more than 89% as shown in Figure 4-28 below.

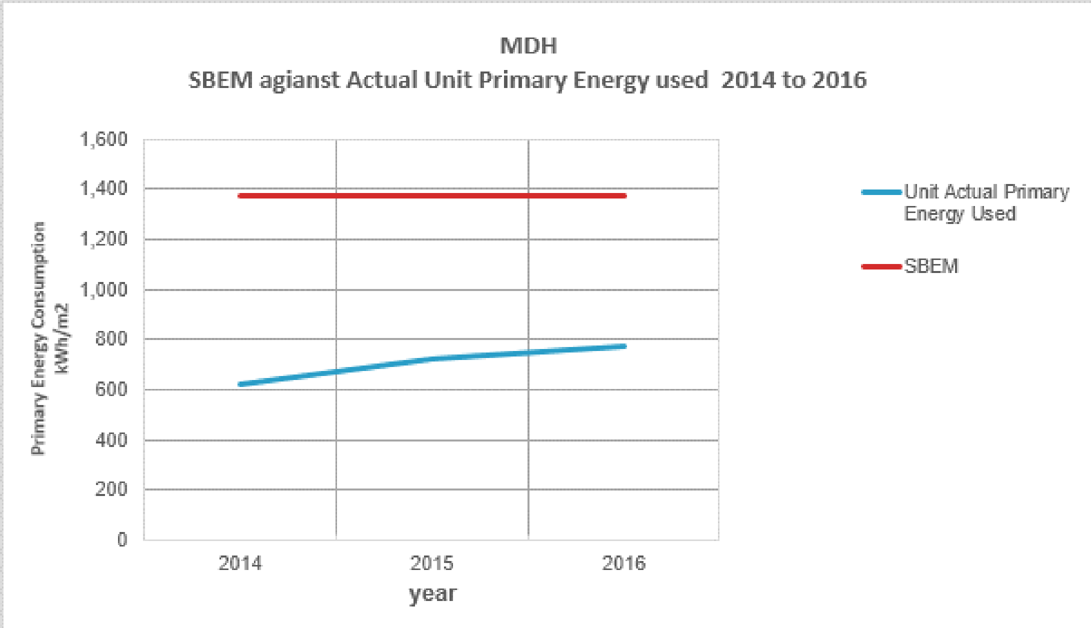


Figure 4-28: Comparison of unit energy used between SBEM and actual for years 2014 to 2016 for Cluster 3 – Mater Dei Hospital

4.4.6 Estimated energy consumption for each sector

The reported difference between the EPC and the actual energy consumption for Mater Dei Hospital is substantial and this notwithstanding that the fuel and electricity readings taken included all the power used for the entire operating hospital with 24 theatres, ITU, CSSD, the Institute of Health Care, administration, staff canteen, etc. It was also not just limited to those systems as catered for in SBEM, but included loads, such as:

- all building services including cold-water distribution equipment, firefighting, reverse osmosis and treatment plants, nurse calls, fire alarm, lifts, pneumatic tubes, medical gases, etc.;
- all medical equipment including MRIs, X-rays, PCs, printers, etc.;
- all small power including the provision of 55 12kW each portable ward food warmers/coolers;
- power used within the class C reconstitution unit for the manufacturing of unique medicines;
- power supply for the construction of the New Oncology Hospital;

- power supply for the construction of the New Medical assessment Emergency Unit;
- power supply to the public cafeterias and market stalls; and
- power supply to third party’s mobile telephony repeaters for Birkirkara area.

As such, this energy performance gap needs to be identified and studied even further. In order to carry out this examination, separate analysis of the five SBEM energy sectors have been individually compared. However, the BMS as designed was not tailor-made for SBEM methodology. This was solved by splitting the long list of monitored equipment into various sectors such as cooling, heating, domestic hot and cold water, ventilation, etc. (as partly shown in Table 4-33 accordingly)

The equipment installed on the primary chilled water circuits had their absorbed current (taken as 80% of its nominal nameplate value) multiplied by the number of hours in operation, and a reasonable estimation of the total annual energy used was calculated.

Table 4-33: Part schedule of primary chilled water pumps to calculate absorbed energy

TAG No	DESCRIPTION	CIRCUIT	BLOCK	PLANT ROOM	FLOW RATE (m^3/h)	RATED VOLTAGE (V)	RATED POWER (kW)	RATED CURR (A)	START CURR (A)	ABSORBED CURR (A)	TOTAL RUNNING HOURS	YEARLY RUINING HOURS	Annual kWh
F02-ACC05-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	18330	1803	10,818
F02-ACC06-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	21660	2130	12,783
F02-ACC07-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	21620	2127	12,759
F02-ACC08-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	19450	1913	11,479
F02-ACC09-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	15320	1507	9,041
F02-ACC010-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	21670	2131	12,789
F02-ACC11-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	18560	1826	10,953
F02-ACC12-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	22530	2216	13,296
F02-ACC13-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	22430	2206	13,237
F02-ACC14-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	24490	2409	14,453
F02-ACC15-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	29190	2871	17,227
F02-ACC16-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	22450	2208	13,249
F02-ACC17-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	25150	2474	14,843
F02-ACC18-P01	PUMP	AC	F2	F209015	7.8	400	7.5	14.9	108.7	6	22410	2388	13,225
										84			**180,153**

4.4.7 Cooling energy consumption

Mainly this load consists of the energy absorbed by the 16 by 1.2MW cool-only packaged water chillers. Since these chillers are not directly metered, the best way sought to calculate their energy consumption was by going through each chiller's 4 compressors' running hours and multiplying this by the nominal absorbed current, voltage and power factor. This result was then repeated for the 16 chillers (ACC1 etc.), as shown in Table 4-34.

Table 4-34: Calculated yearly Energy consumption by the chillers on running hours

REF	MODEL	Comp hours running to date				Taken from literature			Absorbed power per compressor to date				Total absorbed power per chiller from July 2007 to date (approx. 122 months)	Average annual absorbed power per chiller (12months)
		A1	A2	B1	B2	Voltage	Max current drawn at nom per comp	Power Factor	A1	A2	B1	B2		
		Hrs	Hrs	Hrs	Hrs	V	I	cos Ø	MWh	MWh	MWh	MWh	MWh	MWh
ACC1	30GX-358	18,030	17,940	18,300	18,330	400	256	0.86	2,747	2,733	2,788	2,793	11,061	1,088
ACC2	30GX-358	21,520	21,660	17,920	18,720	400	256	0.86	3,279	3,300	2,730	2,852	12,161	1,196
ACC3	30GX-358	21,620	21,540	22,120	21,570	400	256	0.86	3,294	3,282	3,370	3,286	13,232	1,301
ACC4	30GX-358	19,450	18,390	18,900	18,850	400	256	0.86	2,963	2,802	2,879	2,872	11,516	1,133
ACC5	30GX-358	15,320	14,250	11,540	10,970	400	256	0.86	2,334	2,171	1,758	1,671	7,934	780
ACC6	30GX-358	21,670	21,270	17,800	17,910	400	256	0.86	3,301	3,240	2,712	2,729	11,982	1,179
ACC7	30GX-358	18,190	18,350	18,560	16,020	400	256	0.86	2,771	2,796	2,828	2,441	10,835	1,066
ACC8	30GX-358	22,530	22,550	21,330	21,950	400	256	0.86	3,432	3,436	3,250	3,344	13,462	1,324
ACC9	30GX-358	22,430	22,360	22,340	22,250	400	256	0.86	3,417	3,407	3,404	3,390	13,617	1,339
ACC10	30GX-358	23,840	24,490	23,660	24,120	400	256	0.86	3,632	3,731	3,605	3,675	14,642	1,440
ACC11	30GX-358	24,140	29,190	28,480	28,610	400	256	0.86	3,678	4,447	4,339	4,359	16,823	1,655
ACC12	30GX-358	22,110	22,040	22,430	22,450	400	256	0.86	3,368	3,358	3,417	3,420	13,564	1,334
ACC13	30GX-358	25,150	21,570	23,520	21,890	400	256	0.86	3,832	3,286	3,583	3,335	14,036	1,381
ACC14	30GX-358	20,140	20,350	22,030	22,410	400	256	0.86	3,068	3,100	3,356	3,414	12,939	1,273
WCC3	30HXC-325	28,700	27,830	28,840	23,890	400	189	0.89	3,341	3,239	3,357	2,781	12,718	1,251
WCC4	30HXC-325	34,070	32,810	33,140	34,800	400	189	0.89	3,966	3,819	3,858	4,051	15,693	1,544
Total Average Annual Electrical power absorbed by the chillers														**20,283**
Total Average Weekly Electrical power absorbed by the chillers														**390**
Built up area (up to 2015 when EPC certificate was generated)													**m^2**	**249,587**
Calculated unit annual energy usage for cooling													**kWh/m^2 year**	**81**
SBEM-mt COOLING													**$kWh/m^2.yr$**	**158**
PERCENTAGE DIFFERENCE													**Overrated by**	**48.56%**

Operating for 122 months from the day of commissioning and handing over, this gave an average annual energy consumption of 20.28million kWh with a yearly EUI of 81.27kWh/m^2. This result contrasted heavily with the 158kWh/m^2 given by SBEM overrating this sector of the EPC by 48.56%. Though this may seem to be high, the energy as calculated is somewhat generous in the sense that:

a) In view that this assessment was based on the total running hours of each compressor and each of the sixteen1.2MW chillers has four compressors with six-step control logic, means that a compressor can be recording that it is running, but not on full load.

b) The installed HVAC system is a full fresh air single pass throwaway with individual room control having primary and secondary circuits, meaning that some chillers may even be operating on cooling in Winter. Due to favourable ambient conditions in such mild seasons, the power absorbed is much less than the stated nominal, which is design based on 40℃ outside ambient.

When this calculated electrical consumption value was checked with the actual chilled water production as given by the BMS for the 2015 to 2017 period and divided by the chillers coefficient of performance, both results matched closely. This gives confidence, that the approach and calculations used are accurate and reliable.

One must appreciate that every 15 minutes the BMS gives an instantaneous readout of chilled water produced by each of the 16 chillers. This considers the primary chilled water flow and difference in water temperature between entering and leaving at each chiller. Every four readings were added up and averaged to give instant hourly kWh used. Then the total energy consumption was computed on daily, weekly, monthly and yearly production as shown in Figure 4-29 below, which provides the monthly chilled water production for the last two years.

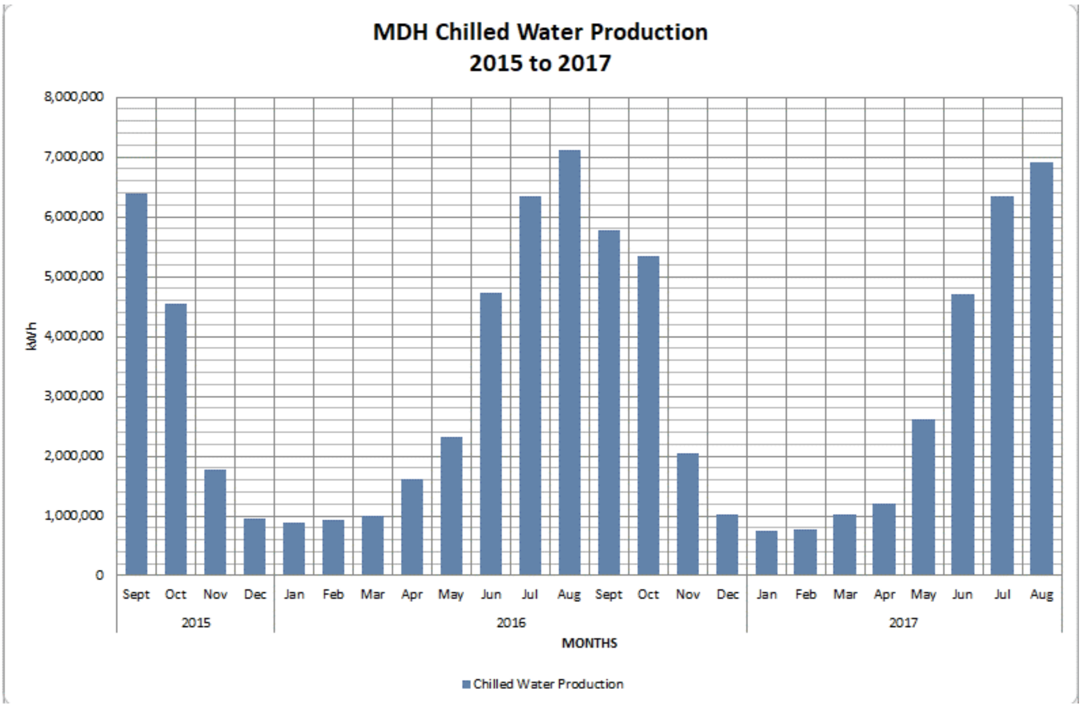


Figure 4-29: Calculated MDH chilled water production

When all the months were added up and divided by 2, this gave a yearly average of 38.57 million kWh per year. This was divided by the manufacturer's seasonal energy efficiency ratio (SEER), which was found to be 1.77 and gave an annual energy consumption of 19.28 million kWh. This is very close to that calculated previously (20.28 million kWh/yr.) using the compressors' running hours within a difference of 5%.

It is to be noted that in SBEM the seasonal efficiency used was better than the one used here for the actual consumption, 2 compared to 1.77. Notwithstanding, the cooling load as calculated by SBEM-mt was much higher than the actual cooling load, as reported above.

4.4.8 Heating energy consumption

The primary heating energy use is mainly associated with the energy used by the four 2MW each, hot water boilers, which operate on gas oil. In view that these boilers provided primary energy for both space heating as well as for the provision of domestic hot water (DHW) and there is no metering separation between them, an initial exercise was carried out to determine the split share of fuel.

From design data the daily DHW load was found to be 380m^3/day of preheated water in the chiller's condensers to 65^{o}C. Thus, allowing for the losses to make up the boiler seasonal efficiencies, pipework losses and for changing from net to gross calorific values, this worked out to be a fuel consumption of 1536m^3/yr or around 65% of the total consumption, as shown in Table 4-35 below.

Table 4-35: Fuel used for DHW in 2015

Design DHW consumption per day	**380**	**m^3/day**
Temp in (condensers' preheating)	20	^{o}C
Temp out	65	^{o}C
Gross CV	6	%
Boiler seasonal efficiency	80	%
Heat loss	10	%
Heat required	71,820,000	kJ/day
Allowance for efficiencies heat loss	79,002,000	kJ/day
Allowance seasonal efficiency	94,802,400	kJ/day
Allowance Gross CV	100,490,544	kJ/day
Weight of fuel per day	2331.57	kg/day
Litres per day	2711.12	l/day
Litres per year	989,560	litres/yr
Total fuel used in 2015	1,536,900	litres/yr
% of fuel for DHW	64.39%	

Consequently, the fuel used for space heating was taken as 35% of the total amount of fuel used which gave a total annual consumption of 5.8million kWh or a unit loading of 23.56kWh/m^2 yr, as shown in Table 4-36 below. This contrasts heavily with 4kWh/m^2 yr given by SBEM. This underrated SBEM part of the certificate by 489%. It is to be noted the seasonal efficiency for the boilers used in SBEM-mt was 0.65. Even if this efficiency was reduced, the SBEM-mt results would still be significantly underrated.

Table 4-36: Annual energy used for space heating production

HEATING - BOILERS - Fuel Oil - 35%			
DESCRIPTION	**REF**	**Annual Energy consumed** **kWh**	**The energy used per unit floor area** **kWh/m²**
Year	2015		
Fuel type	gas oil		
Consumption	litres	547,340	
Density	kg/m³	850	
Weight of fuel	kg	465,239	
Gross Calorific value	MJ/kg	45.5	
Total energy consumed per year	kJ	21,168,356,136	
Total energy consumed per year	**kWh**	**5,880,099**	**23.56**
SBEM-mt HEATING			**4**
PERCENTAGE DIFFERENCE		**Underrating**	**- 489%**

4.4.9 Auxiliary equipment

As for the auxiliary energy use for ventilation and pumping, the installed equipment was divided into various sections to produce chilled water, hot water and ventilation. Overall, these gave an annual energy use of 5.96, 3.3 and 12.52 million kWh per year, as shown in Table 4-37 below, for a total energy use intensity EUI of 89.46kWh/m².yr against the 176kWh/m².yr as predicted by SBEM. This amounted to an overrating of around 49%.

Table 4-37: Annual Energy consumption from Auxiliary equipment

AUXILIARIES			
PRIMARY CHILLED WATER			
DESCRIPTION	**REF**	**Annual energy consumed kWh**	**Energy used per unit floor area kWh/m²**
Chilled water primary pumps	ACC	180153	
Condenser coolers & pumps	WCC	738,114	
Chilled water secondary pumps	CHW	2,172,480	
Chilled water pumps AHUs	CHW1	2,729,616	
Chilled water pumps chilled beams	CHW2	148,009	
TOTAL		**5,968,373**	**23.91**
CENTRAL HEATING WATER			
DESCRIPTION	**REF**	**Annual energy consumed kWh**	**Energy used per unit floor area kWh/m²**
Fuel oil pumps	FO	18,571	
Boilers & pumps	BO	301,344	
High temperature hot water pumps	HTW	573,570	
Primary hot water before mixing valve	HW1	275,414	
Primary hot water after mixing valve	HW2	103,018	
Duct heaters	DHE	656,640	
Hot water return pumps	HRW	1,902,882	
TOTAL		**3,831,439**	**15.35**
VENTILATION			
DESCRIPTION	**REF**	**Annual energy consumed kWh**	**The energy used per unit floor area kWh/m²**
Supply air AHUs	SA	6,591,444	
Extract air AHUs	EA	3,434,200	
Dirty extract air AHUs	EAD	1,573,366	
	EA-PM	3,854	
Electric heaters	EH	52,560	
Heat recovery	HR	26,140	
Humidifiers	HU	435,520	
Outside air flow	OA	140,861	
Transfer fans	TF	270,509	
TOTAL		**12,528,455**	**50.20**
TOTAL FOR AUXILIARY		**22,328,267**	**89.46**
SBEM-mt EPC AUXILIARY			**176**
PERCENTAGE DIFFERENCE			**49%**

4.4.10 Domestic Hot Water

The energy associated with the remaining 65% of fuel used was added to the energy consumed by the domestic hot water circulation pumps and other heating equipment to get an annual energy use of 10.32 million kWh for a unit floor loading of 41.36 kWh/m^2.yr. This consumption overrated SBEM by nearly 27%, as shown in Table 4-38 below.

Table 4-38: Annual Energy consumption from Domestic hot water

DOMESTIC HOT WATER			
DESCRIPTION	**REF**	**Annual Energy consumed kWh**	**The energy used per unit floor area kWh/m²**
DHW pumps primary	DHW	63,072	
DHW pumps secondary	DHW1	841	
DHW pumps return	DHWR1	69,309	
DHW pumps return mortuary	DHWR2	841	
TOTAL		**134,063**	**0.54**
DHW – BOILERS – Fuel Oil – 65%			
DESCRIPTION	**REF**	**Annual Energy consumed kWh**	**The energy used per unit floor area kWh/m²**
Year	2015		
Fuel type	gas oil		
Consumption	litres	989,560	
Density	kg/m³	860	
Weight of fuel	kg	851,022	
Gross calorific value	MJ/kg	43.1	
Total energy consumed per year	kJ	36,679,048,560	
Total energy consumed per year	**kWh**	**10,188,625**	**40.82**
TOTAL for DHW		**10,322,688**	**41.36**
SBEM-mt EPC DHW (kWh/m².yr)			**57**
PERCENTAGE DIFFERENCE			**27%**

4.4.11 Lighting

The approach adopted to achieve the actual annual energy used by lighting was to identify each of the 30,080 installed luminaires on a block by block, its installed power known and multiplied by the hours of operation as per its schedule. This consumption practically covers all lamps within the hospital except for the street and surface lighting, which are also included in the energy consumption and calculated within the electricity bill. The unit annual loads on a block-by-block tally are shown in Table 4-39 below, which averaged to an EUI of 42kWh/m^2.yr, as compared to the 44 kWh/m^2.yr, as given by SBEM-mt. This amounted to an overrating of around 4.5%.

Table 4-39: Annual Energy Consumption from lighting

BLOCK	Total Blocks Floor Area m^2	Total Daily Energy Consumed (Installed Wattage x operating hrs)	Total Yearly Energy Consumed	Unit Loading
		kWh	kWh	kWh/m^2
A1	4,709	788	**287,503**	**25**
A2	4,746			
A3	2,017			
B	15,789	2,361	861,879	55
C	36,319	6,573	2,399,141	66
D	85,396	8,994	3,282,693	38
E	16,503	3,260	1,189,807	72
F	11,347	612	223,492	20
H	2,022	101	36,810	18
S3	241	Substations		
S2	117	Substations		
K1	46	Underground tanks		
CP	53,096	4,346	1,586,226	30
Total area each level	**232,347**		**9,867,550**	**42**
SBEM-mt LIGHTING				**44**
PERCENTAGE DIFFERENCE				**4.5%**

4.4.12 Discussion – Cluster type 3

In the above calculations when one compares the total electrical energy used during 2015 as taken from the electricity utility bills (47.39MkWh) to that as analytically calculated above only for SBEM systems (30.28.MkWh), this works out to be around 68% of the total value as shown in Table 4-40 and Figure 4-30. When one considers the other equipment of high-energy consumption such as IT, medical, food warmers etc. but not catered for, this percentage is relatively high and in favour of SBEM.

Furthermore, in view that the equal split of fuel used between that for space heating and DHW gave a heavily overrated percentage in space heating and a 23% underrating in DHW, this share split was again recalculated on a 35%-65% proportion to match the domestic hot water usage as designed. In fact, and as explained in the discussion for Cluster 2, such space heating in Malta is not required due to our mild Winter climate.

Table 4-40: Annual energy usage at MDH

Year 2015	**kWh**
Total Electrical Energy as per electricity bills	47,389,533
Electrical Energy for SBEM systems as analytically calculated	30,285,074
Fuel Energy for SBEM systems as analytically calculated	16,068,724

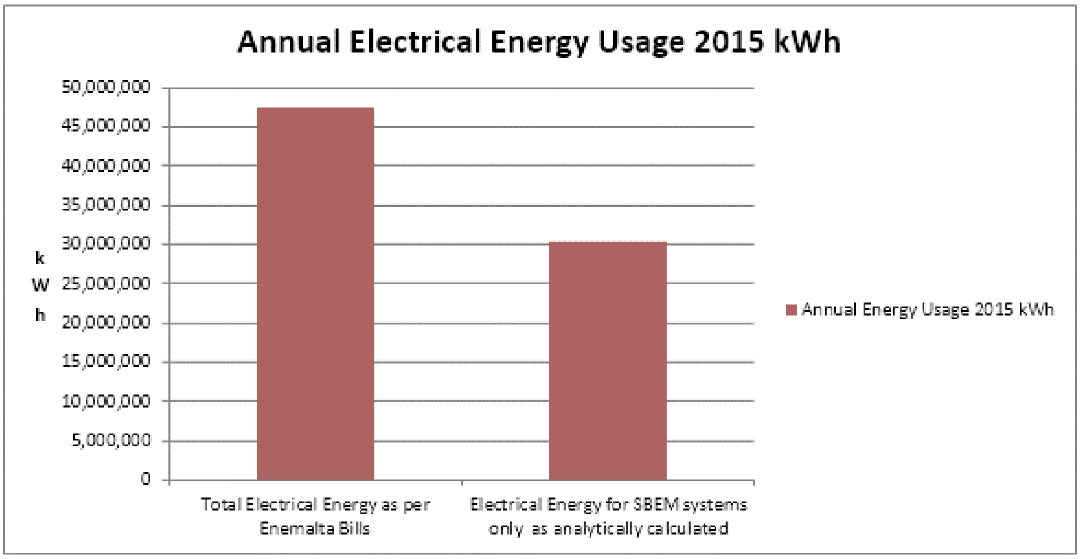


Figure 4-30: Electrical energy usage comparison SBEM-mt vs total electrical energy consumption as measured at Mater Dei

Finally, the overall comparison of the unit energy consumptions on a system by system, is given in Table 4-41 below.

Table 4-41: Overall performance for SBEM as compared to the actual energy usage of MDH

Unit Annual Energy Consumption

System	Average kWh/m² yr.		Percentage rating by SBEM as compared to actual	
	SBEM	Actually measured & estimated		
Heating	4	23.56	-489%	Underrating
Cooling	158	81.27	49%	Overrating
Auxiliary	176	89.46	49%	Overrating
Hot water	57	41.36	27%	overrating
Lighting	44	42.47	4.5%%	overrating
Total	440	278.12	57.85%	overrating

This calculation gave an overall overrating certificate of around 57.85%, with performance on a system by system shown graphically in Figure 4-31 below.

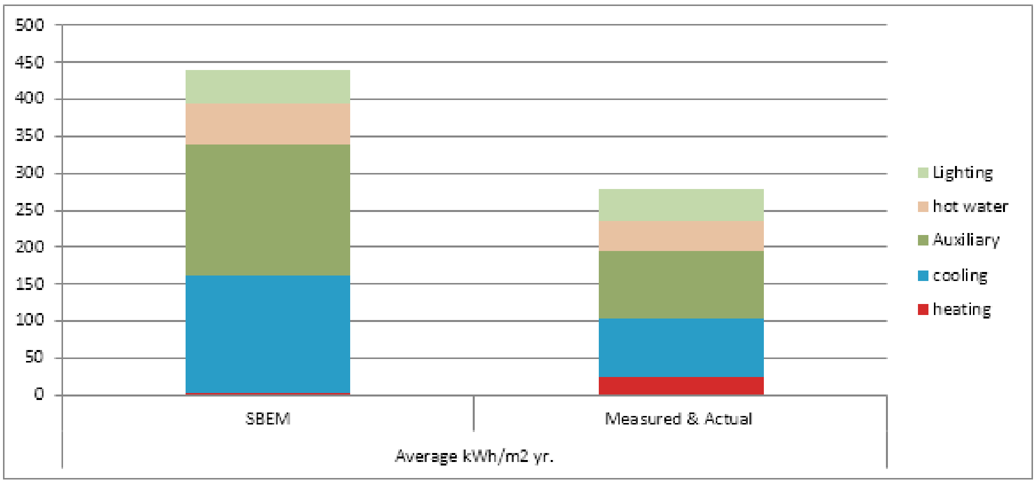


Figure 4-31: Energy performance as predicted by SBEM vs actual on-site energy performance for Mater Dei Hospital

4.5 Summary

Notwithstanding the high overrating given by SBEM-mt for Cluster 1, where practically building services are inexistent, this gap can be related to irregular energy gain or loss calculations through the building structures. Meanwhile, energy consumption as predicted for Clusters 2 and 3 are heavily swinging from an underrating of around 64% for Cluster type 2 buildings, such as offices, to an overrating of around 58% for more complex Cluster type 3 buildings; such as Mater Dei Hospital, as shown in Table 4-42 and Figure 4-32 below.

Table 4-42: Percentage difference between SBEM and actual for differ clusters

Building type	Percentage Rating	
Cluster type 3	58%%	Overrating
SBEM	Datum	Actual
Cluster type 2	-64%	Underrating

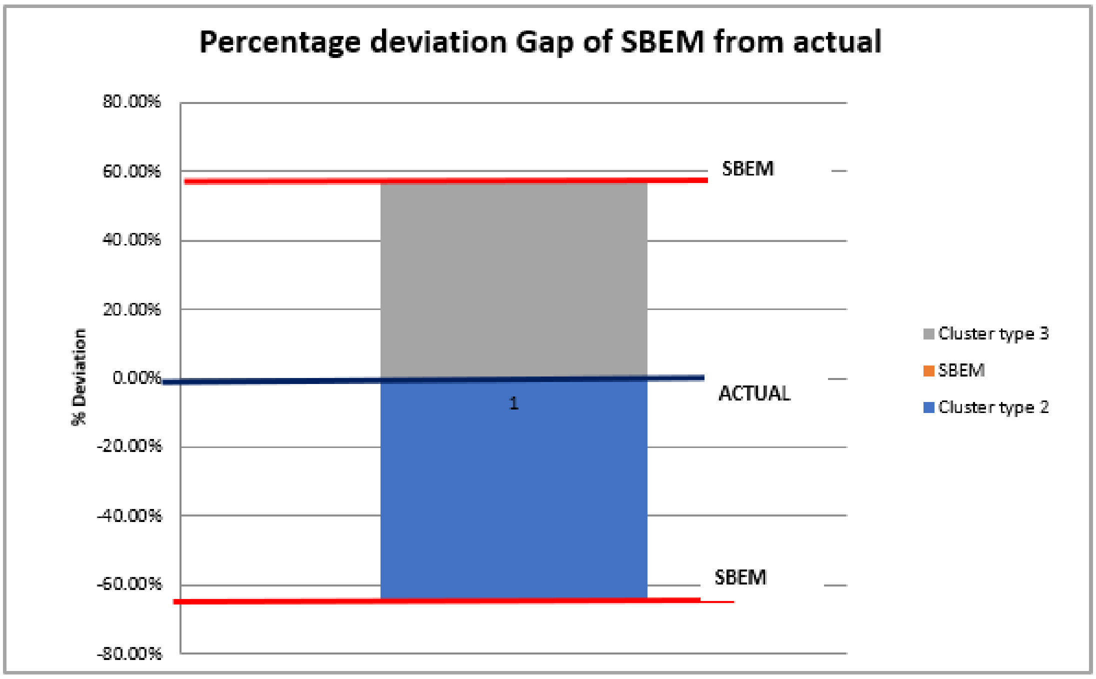


Figure 4-32: Graphical representation of the performance gap for Cluster type 2 and 3 from actual EUI

Therefore, there is a mismatch between the expectations around the energy performance of buildings and the reality of the actual energy consumption. This difference between expected and realised energy performance has come to be known as the *Performance Gap*.

This phenomenon is not restricted to Malta but has been observed as far afield as other countries including the UK, US and Australia. However, in the UK, the difference is the other way around, and the buildings use more energy than that predicted as shown in Figure 4-33, taken from CIBSE *TM54: Evaluating Operational Energy Performance of Buildings at the Design Stage* [138].

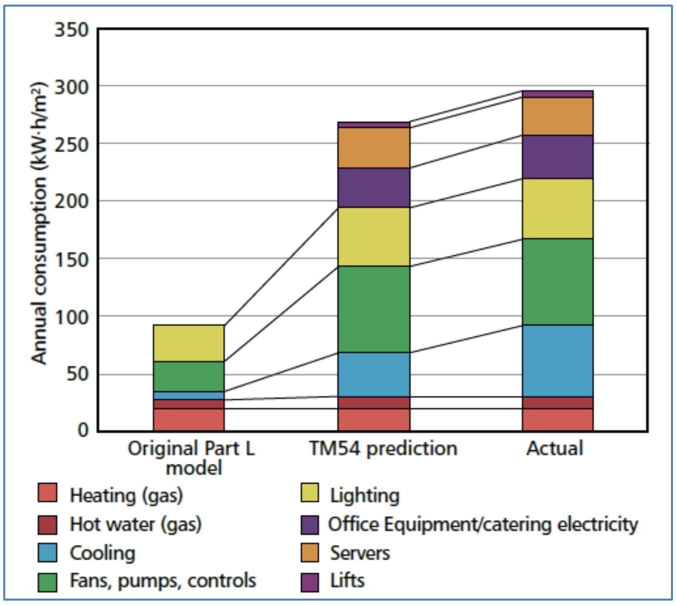


Figure 4-33: Comparison of compliance, design modelling and actual energy use [73]

One must consider that SBEM, as is amply explained in its technical and operating manuals, is primarily an Asset Rating methodology that can be performed on both buildings at the design or completed habitat stages. It is more to check if a building has been built to some type of standard; such as in the UK regarding to Part L2A, as shown in Figure 4-33.

5 PROPOSED SOLUTION FOR BENCHMARKING NON-RESIDENTIAL BUILDING CATEGORIES FOR MALTA

5.1 Introduction

Following verification of the existence of the *Performance Gap* between the EPCs and the actual energy consumption for the three clusters of buildings, this chapter focuses on proposing a solution to produce good practice benchmarks for 29 categories of non-residential buildings, using a highly flexible template that has been devised, based on the degree-day method.

As opposed to typical benchmarks, which are the fruit of statistical surveys of existing buildings, the benchmarks derived from this thesis are best practice. They already take into consideration, to a large extent, the practical and feasible measures that can be incorporated within buildings to make them operate at high efficiency.

These benchmarks can be used as Key Performance Indicators (KPIs) to quantify and qualify the energy use and efficiency within buildings. They also aim to create a stable return of knowledge from different types of buildings for building designers, energy managers and policy makers.

As already discussed in Chapter 2, the weather-independent component of energy consumption for every category within non-residential buildings is to a certain extent constant and controlled, and this is generally the same all over the world. This is influenced by the class, type of design, occupation, operation and maintenance generally for the well-being of occupants, as well as for visual and acoustic comfort, while the remaining part of energy use is weather-dependent and is needed to achieve the required thermal comfort conditions. This is generally known as the energy signature of buildings, as shown in Figure 5-1, for cold climates.

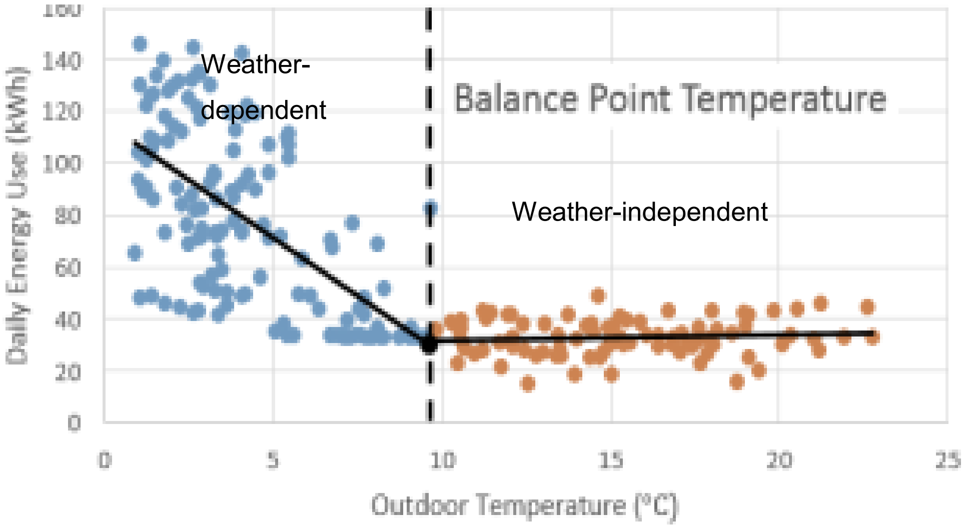


Figure 5-1: Energy signature daily energy use vs outdoor temperature for different buildings in cold countries [139]

Based on this principle, this research adapts the well-established UK best practice benchmarks, and harmonises them to Malta's local predominantly cooling load climate, using the degree day methodology, as well as the additional latent load in Summer cooling period.

In the UK, benchmarks for energy consumption prediction in buildings are given in CIBSE TM46: *Energy benchmarks* [61]. These are generally referred to in the Display Energy Certificates (DECs) for selected building types in the following categories:

a) Education – Schools
b) Entertainment
c) Hospitals
d) Local authority buildings
e) Offices
f) Primary health care
g) Public buildings
h) Sports and recreation

These benchmarks are a direct transfer from the latest edition (2014) of CIBSE Guide F: *Energy Efficiency in Buildings*, Table 20.1 [69], which in itself is a comprehensive study on the recommended approach to design, install and run a building to complement the five preceding guides namely A, B, C, D and E [123], [133], [140], [141] and [142].

The stages devised to adapt the UK's best practice benchmarks to Malta's climate, may be summarised as follows:

a) Separate and identify the weather-dependent and weather-unrelated components for each EUI of the UK best practice benchmarks.
b) Calculate the degree-days for Malta and harmonise linearly the weather-dependent EUIs for each of the 29 categories of non-residential buildings.
c) Calculate the latent load due to ventilation in summer when cooling equipment is in operation. This caters for three components, air for breathing, ventilation to remove personnel emissions, ventilation to remove emissions from material, use of equipment and infiltration.
d) Add the outputs of the adjusted degree-days EUIs to the latent load to get the corrected weather-related energy use intensities for that particular benchmark.
e) Add the weather-dependent to the weather-independent components to get the total good practice EUI benchmark.
f) Repeat this process for each categorised building.

Figure 5-2 provides a flow chart of the template that has been devised to determine the "good practice" benchmarks for Malta. Each component of the flow chart is linked to particular sections within this Chapter, where the detailed workings were carried out. A larger version of the flow chart is found in Appendix D.

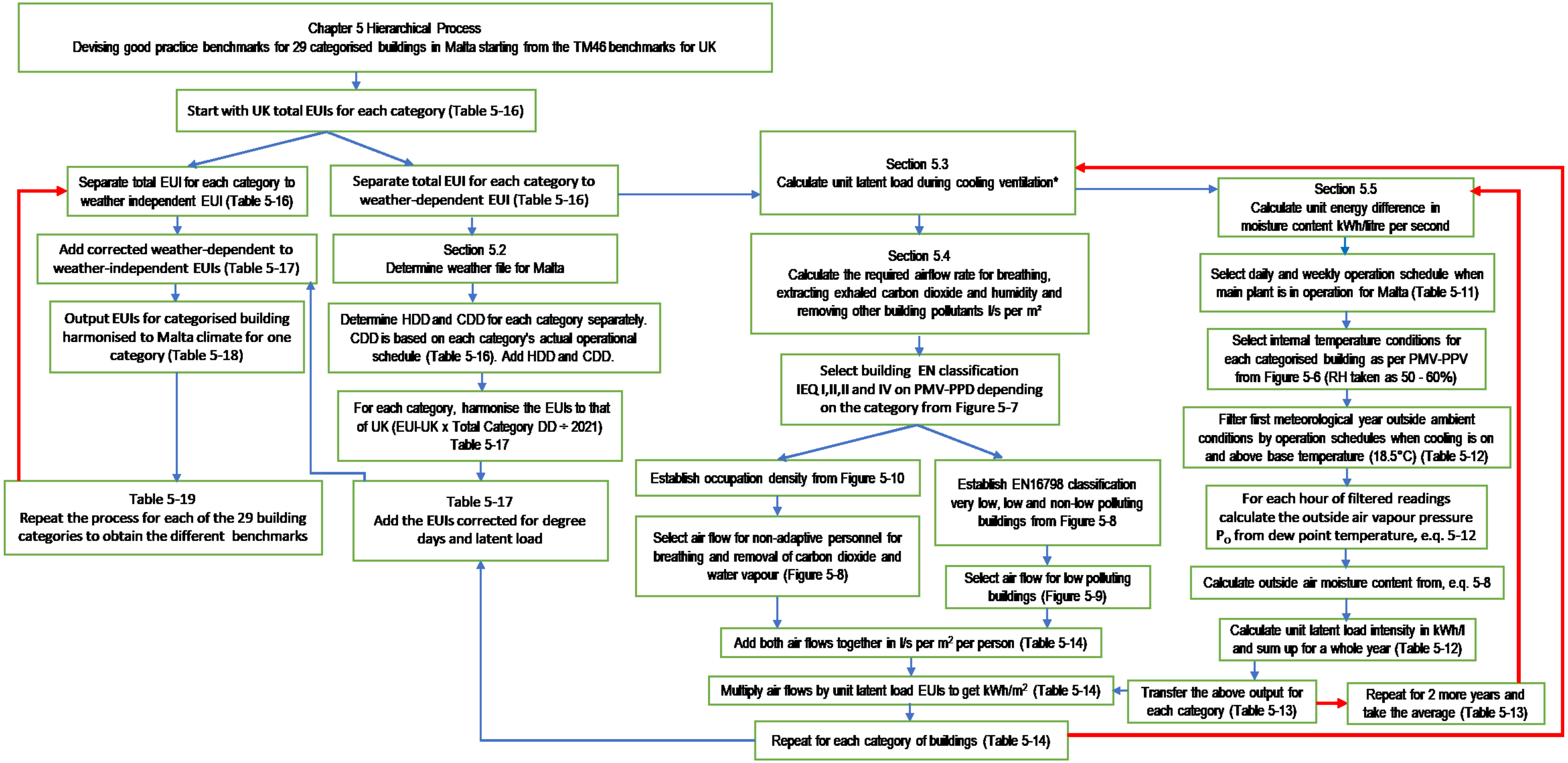


Figure 5-2: Flow chart showing the template that has been devised to determine good practice benchmarks for Malta

5.2 Calibration of unit energy use to suit local climate conditions

5.2.1 Calculation of the total number of degree days for Malta.

The amended EPBD [2018/844] [5] clearly sets out that:

> *Member States shall describe their national calculation methodology following the national annexes of the overarching standards, namely ISO 52000-1,52003-1, 52010-1, 52016-1, and 52018-1, developed under mandate M/480 given to the European Committee for Standardisation (CEN). This provision shall not constitute a legal codification of those standards*.

While EN ISO 52003-1 standard is on building Energy Performance Indicators (KPIs) requirements, standard EN ISO 52010-1 is a requirement for each Member State to compile and convert climate data for same base energy use calculations for the provision of a Typical Mereological Year (TMY) [143]. This database of common typical weather data is not yet available for Malta. However, this thesis has taken into consideration the impact of climate change on weather, by using three very recent years of hourly weather data for Malta to carry out the full procedure of determining the benchmarks. An average was then taken to be used in the calculations for determining the best practice EUI benchmark for each category of non-residential buildings. As will be illustrated later, the difference of results between the three years was very small.

In calculating the total degree days for Malta, local meteorological data was provided by the Meteorological Office of the Malta International Airport [144]. This included daily hourly readings for dry-bulb temperature (T), dew-point temperature (T_d), relative humidity (RH) and atmospheric pressure (P_{at}).

Workings were carried out to compile the outdoor temperatures in a Microsoft Excel worksheet to return only the standard base temperatures of 15.5°C for heating (HDD) and 18.5°C for cooling (CDD), as shown in Table 5-1.

Table 5-1: Degree-days for years 2010, 2016 and 2017 using local meteorological data

Using Excel Programme				
Year	2010	2016	2017	3-year average
HDD 15.5 °C	296	256	343	298
CDD 18.5 °C	919	1098	1144	1054
Total	1215	1354	1487	1352

The year 2010 was chosen since it is the weather database included in the Maltese SBEM-mt [55] programme for energy performance calculations. The average number of total degree-days from this analysis is 1352.

To check the accuracy of this data, these values were compared to the degree-days as given in the ASHRAE 2017 *Fundamentals Handbook* [105], which includes Malta among 8,118 weather stations from all over the world, as partly shown in Figure 5-3.

2017 ASHRAE Handbook - Foundamentals (SI)

MALTA LUQA, MALTA (WMO: 165970)

Lat:35.857N Long:14.478E Elev:91 StdP: 100.23 Time zone:1.00 Period:90-14 WBAN:99999

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB 99.6%	Heating DB 99%	Humidification DP/MCDB and HR 99.6% DP	99.6% HR	99.6% MCDB	99% DP	99% HR	99% MCDB	Coldest month WS/MCDB 0.4% WS	0.4% MCDB	1% WS	1% MCDB	MCWS/PCWD to 99.6% DB MCWS	PCWD
2	6.9	7.9	0.0	3.8	9.9	1.8	4.3	10.3	14.1	12.7	12.6	12.5	3.3	280

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

Hottest Month	Hottest Month DB Range	Cooling DB/MCWB 0.4% DB	0.4% MCWB	1% DB	1% MCWB	2% DB	2% MCWB	Evaporation WB/MCDB 0.4% WB	0.4% MCDB	1% WB	1% MCDB	2% WB	2% MCDB	MCWS/PCWD to 0.4% DB MCWS	PCWD
8	8.1	34.1	21.3	32.3	21.8	31.1	22.0	25.2	28.7	24.7	28.1	24.1	27.6	3.6	300

Dehumidification DP/MCDB and HR 0.4% DP	0.4% HR	0.4% MCDB	1% DP	1% HR	1% MCDB	2% DP	2% HR	2% MCDB	Enthalpy/MCDB 0.4% Enth	0.4% MCDB	1% Enth	1% MCDB	2% Enth	2% MCDB	Extreme Max WB
24.2	19.3	26.6	23.8	18.8	26.4	23.0	18.0	26.1	77.6	28.5	75.1	28.1	72.9	27.6	30.6

Extreme Annual Design Conditions

Extreme Annual WS 1%	2.5%	5%		Extreme Annual Temperature Mean Min	Mean Max	Standard deviation Min	Standard deviation Max	n=5 years Min	n=5 years Max	n=10 years Min	n=10 years Max	n=20 years Min	n=20 years Max	n=50 years Min	n=50 years Max
11.3	10.0	9.0	DB	4.6	37.6	0.9	2.2	4.0	39.3	3.4	40.6	2.9	41.8	2.3	43.5
			WB	2.9	26.7	1.2	1.2	2.1	27.5	1.4	28.2	0.7	28.9	-0.2	29.8

Monthly Climatic Design Conditions

		Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperatures, Degree-Days and Degree-Hours	DBAvg	19.2	12.7	12.3	13.8	16.0	19.7	23.8	26.5	27.2	24.5	21.5	17.6	14.1
	DBStd	5.65	1.85	2.12	2.13	1.91	2.27	2.58	1.94	1.77	1.88	2.18	2.27	2.14
	HDD10.0	9	3	4	1	0	0	0	0	0	0	0	0	1
	HDD18.3	744	176	170	142	73	11	0	0	0	0	2	39	131
	CDD10.0	3359	86	68	118	180	299	414	512	532	436	357	229	129
	CDD18.3	1053	0	0	1	3	52	165	253	273	186	101	18	1
	CDH23.3	7858	0	0	4	8	209	1161	2336	2664	1156	309	12	0
	CDH26.7	2543	0	0	1	1	35	378	889	996	218	26	0	0

Figure 5-3: Degree Days for Malta from ASHRAE Fundamentals 2017 [105]

However, the heating and cooling degree-days given in this guide are compiled for base temperatures of 10 and 18.3°C. In such a case, as shown in Table 5-2, extrapolation from this data, results in annual CDD differing by about 7%, which is reasonably close to the value derived from Table 5-1.

Table 5-2: Total degree-days comparison as calculated from local meteorological data and as reported in ASHRAE 2017 [83]

	Using local metrological data				ASHRAE 2017	Difference	
Year °C	**2010**	**2017**	**2018**	3-yr. average			**Percentage difference**
HDD 10	8	22	8	12	9	3	28%
HDD15.5						Interpolation	2%
HDD 18.3	588	786	637	670	744	-74	-11%
CDD 10	3562	3416	3518	3498	3359	139	4%
CDD 18.3	1113	1150	1117	1127	1053	74	7%
HDD18.5						Extrapolation	7%

To confirm the resulting 1,352 total degree-days compiled from the meteorological data, this result was compared to those projected by the international DD web-based calculator as generated by *Degreedays.net* from BizEE Software company [145], for the same 36 months, as shown in Figure 5-4

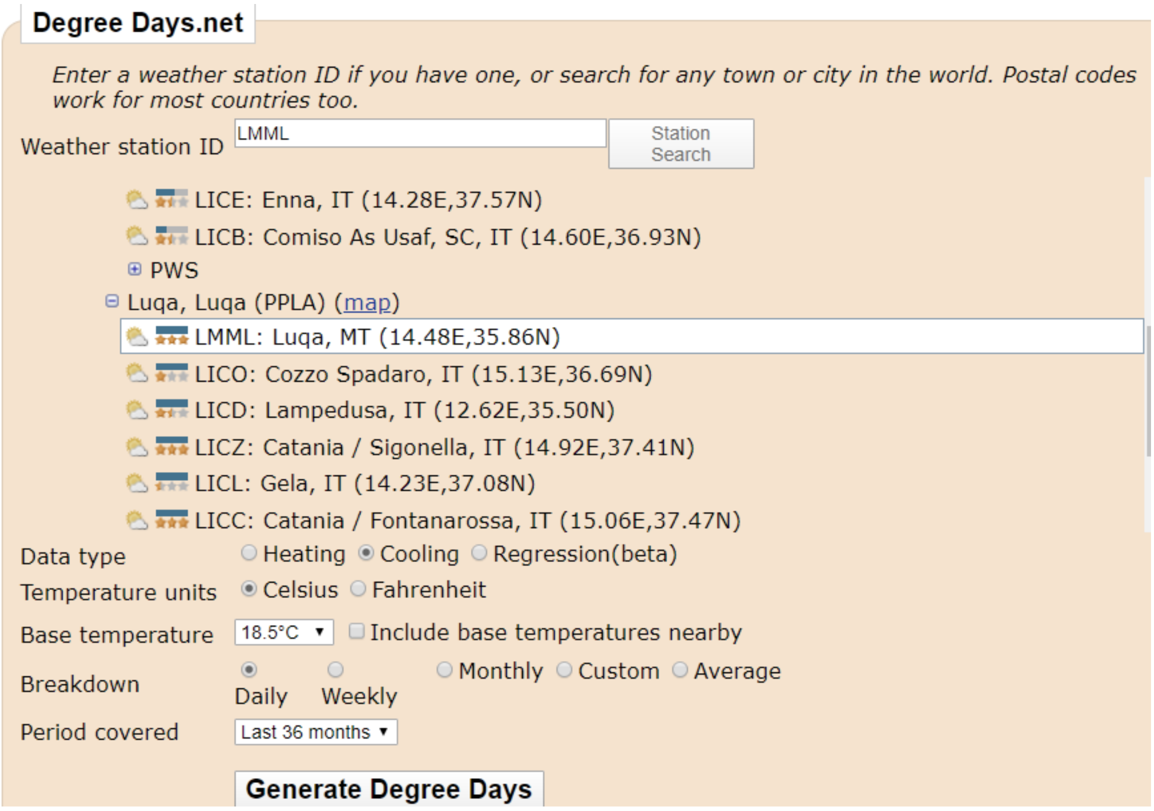


Figure 5-4: Degree Day calculator using the BizEE Software [145] for worldwide locations

Based on the standard base temperature, this software resulted in a total annual degree day for Malta of 1473. As shown in Table 5-3 when these are averaged and compared to the values in Table 5-1, this results in an overall average for the annual degree days 1412 for Malta.

Table 5-3: Comparison of local degree days with online calculator [108]

Using Excel program for local meteorological data					Using *DegreeDays.net* software	**Average Total Degree Days**
Year	2010	2016	2017	3-year. Average	3-year Average	
HDD 15.5	296	256	343	298	336	**1412**
CDD 18.5	919	1098	1144	1054	1137	
Total	**1215**	**1354**	**1487**	**1352**	**1473**	

At this stage, it is important to note that the UK value of 2,021 HDD is the average number of DD across the UK monitored for 45 years from 1961 to 2006, with regional values varying from 1800 to 3200, as shown in Figure 5-5 below taken from CIBSE Guide F, Chapter 19 [69].

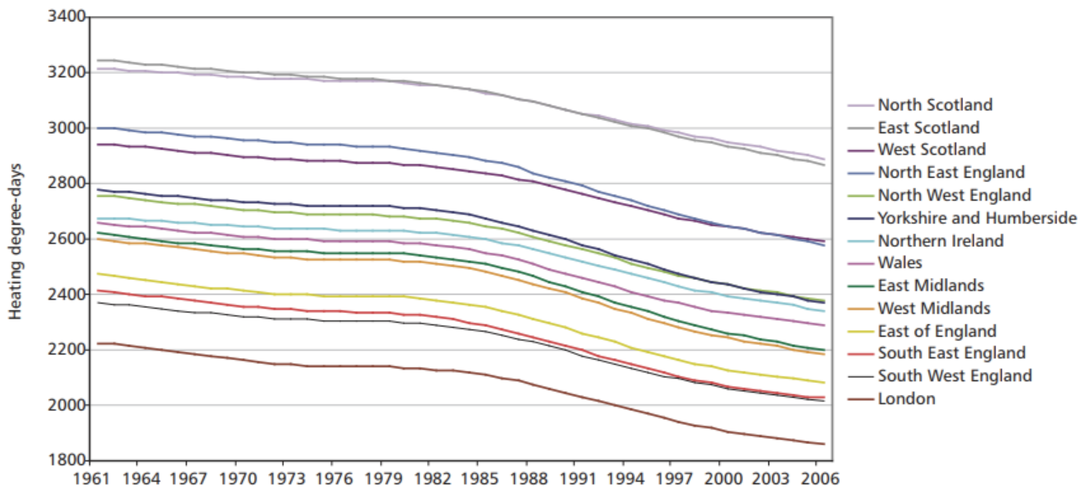


Figure 5-5: UK annual heating DD, by region, from 1961–2006 [69]

On the other hand, Figure 5-6, for the same period shows that the CDD across all the regions of the UK only varied between 0 and 50. Thus, only the HDD were considered when computing the UK good practice benchmarks, because the inclusion of CDD would have added to the complexity of the exercise, as this would require inclusion of the sensible cooling load and the latent cooling load due to ventilation and infiltration from outside air.

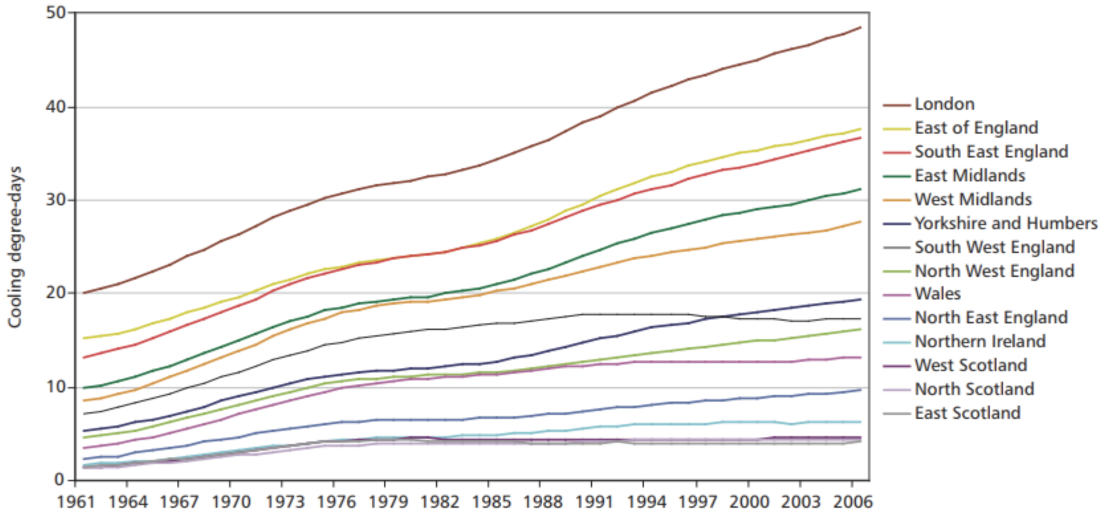


Figure 5-6: Annual cooling degree-days for the UK from 1961 to 2006 [69]

As such for the UK a total of 2,021 DD is considered as a conservative average for the whole year.

For the degree-day methodology in a predominantly cooling demand country such as Malta, the respective categorised buildings are similar to those obtained from the UK good practice benchmarks, corrected to Malta's total annual degree days, with the added energy load due to moisture removal for the cooling mode.

5.3 Energy Use Intensities (EUIs) due to ventilation latent load

Air is the working fluid for all air-conditioning processes. In such systems, outdoor air is conditioned by passing it through various system components, which may include coolers, heaters, dehumidifiers, etc. All these consume energy and as given in ASHRAE Fundamental [105] *Energy Estimating and Modelling Methods* the DD methodology requires that the energy consumed during cooling also considers the latent load associated with the required ventilation airflows, besides the sensible cooling requirements.

The extra ventilation energy load per square metre of useful floor area is worked out on the unit building ventilation rate, multiplied by the hourly difference in moisture content between outdoor and indoor air for the daily number of hours during which the cooling equipment is operating above the standard cooling base temperature of 18.5°C, as given by Equation (5-1) below [105].

$$\mathbf{Q_{latent}} = \mathbf{m h_{fg}}(\mathbf{W_o} - \mathbf{W_i}) \tag{5-1}$$

Where

Q_{latent}	=	Hourly latent cooling load, kWh/m^2
m	=	Hourly infiltration (total airflow), kg/s per m^3
h_{fg}	=	The heat of vaporisation of water, kJ/kg
W_o	=	Outdoor moisture content (humidity ratio) (hourly)
W_i	=	Indoor moisture content (humidity ratio) (hourly)

5.4 Ventilation rates for non-residential buildings

Indoor air quality (IAQ) in buildings has to meet a level suitable for a healthy environment to ensure the wellbeing of occupants. This is achieved through proper ventilation and filtration of the incoming air. This is taking precedence especially following the breakout of the coronavirus pandemic known as COVID-19.

In non-residential buildings, the ventilation rates and standards are usually higher than those in residential buildings, since these buildings often have more complex floor plans that require the provision of mechanical ventilation to all zones. Usually, outdoor air is treated in air handling units or similar equipment and supplied to the different zones via a network of ductwork, diffusers and grilles. Treatment of the air may include filtration, heating, cooling, humidification and dehumidification.

So, in such buildings it is necessary to ventilate and supply good quality air because this is required:

a) To breathe;
b) To remove or dilute carbon dioxide due to exhalation;
c) To remove or dilute water vapour due to exhalation;
d) To remove or dilute pollutants emitted by internal activities and the building material itself or adjacencies.

Therefore, in short, in a standard regulatory framework for non-residential buildings, a minimum ventilation rate per person for the above four requirements will need to be calculated separately and then added together [112]. This is calculated based on Equation (5-2), taken from EN16798-1 [146]:

$$\mathbf{V_{tot}} = \mathbf{n.q_p} + \mathbf{A_R.q_B} \qquad (5\text{-}2)$$

Where

V_{tot} = Total ventilation rate for the breathing zone, l/s

n = Design value for the number of the persons in the room

v_p = Ventilation rate for occupancy per person, l/ (s person)

A_R = Floor area, m^2

v_B = Ventilation rate for emissions from building, l/ $(s \cdot m^2)$

5.4.1 Air for breathing of non-adaptive personnel and body pollutants removal

In his book *Thoughts on the Human Body* [147], Dr J Ochsner describes the human body as a perfect burning machine. Therefore, requiring oxygen, as detailed below.

a) Control of oxygen for breathing:

In simple terms, humans need to breathe in air, so that oxygen interacts with the glucose in the blood to produce energy, which eventually releases carbon dioxide and water vapour to the space around. In fact:

$$glucose + oxygen \rightarrow carbon\, dioxide + water\, vapour + energy$$

$$\boldsymbol{C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O + \mathbf{Energy}} \quad (5\text{-}3)$$

The inputs and outputs of respiration are deconstructed such:

- During inhalation – atmospheric air which is mainly made up of 21% O_2, 78% N_2, 0.03% CO_2
- During exhalation – air composed of 16% O_2, 79% N_2, 4% CO_2 and water vapour.

This oxygen intake depends on an individual's activity. An adult male typically breathes 16 times per minute, each time inhaling around half a litre of air, and up to 8 l/min or 0.13 l/s per person, consuming around 250 – 350ml/min of oxygen. Consequently, the required amount of oxygen would need to be supplied to indoor spaces to cater for this demand.

There are three other factors that need to be considered, namely carbon dioxide, water vapour and pollutant from indoor objects that all need to be expelled from the room.

b) Control of carbon dioxide pollutant

Typical total CO_2 production in rooms, caused mainly by human activities are shown in Table 5-4 below, taken from ASHRAE *Fundamentals Handbook 2017* [105].

Table 5-4: CO_2 production by personnel at different activity levels [83]

Activity	CO_2 production (l/h)
Seated man	13
Light activity	19
Medium activity	60
Heavy labour	77

On the other hand, internal environment standard EN 16798-1 [146], as shown in Table 5-5 provides the recommended indoor CO_2 concentration in ppm above the standard external ambient of air of 350ppm for various categorised buildings.

For such concentrations, the design ventilation rate is calculated based on a mass balance formula between outdoor air and the pollutant, as given in Equation (5-4) below. Values in brackets show the required outside air ventilation rates for each particular categorised building.

Table 5-5: Acceptable design limits for CO_2 concentrations in various categories of buildings [146]

Category	Corresponding CO_2 concentration above outdoors in PPM for non-adapted persons
I	550 (10)
II	800 (7)
III	1 350 (4)
IV	1 350 (4)

This gives:

$$\boldsymbol{V_s} = \frac{\boldsymbol{m_{co2}}}{\boldsymbol{\Psi_{max} - \Psi_e}} \tag{5-4}$$

Where:

V_s	=	supply air flow rate necessary to keep CO_2 concentration at or below the required level	[m³/h]
m_{CO2}	=	CO_2 production	[l/h]
Ψ_{max}	=	maximum CO_2 concentration in interior air (1200 ppm)	[ppm]
Ψ_e	=	outside air concentration of CO2 (350 ppm)	[ppm]

Thus, for example, light activity work with a default maximum interior concentration of 1200ppm of CO_2 and using outside ventilation air gives:

$$= \frac{19l/h}{(1200 - 350)} = 22.4m^3/h \ per \ person$$

$$which \ is \ equivalent \ to \ 6.22l/s \ per \ person$$

c) Control of water vapour pollutant

Water vapour is produced indoors by evaporation from the skin, when breathing, when cooking or when using hot water, which will need to be removed.

Table 5-6 taken from ASHRAE *Fundamental Handbook* [105] gives the water vapour production rate for various human activities.

Table 5-6: exhalation water vapour production [105]

Activity	Water vapour production [g/h]	Source	Water vapour production [g/h]
Stationary	30	Bathroom with bath	about 700
Light activity	40-200	Bathroom with shower	about 2600
Medium activity	120 to 300	Kitchen during cooking	600 to 1500
Heavy labour	200 to 300	Kitchen with gas cooker	1500 g per 1 m^3 gas

Assuming a light/medium activity with $140g/h$ of vapour emission and a difference in the moisture content of outdoor air to indoor air of 8.8g per kg of dry air as read from psychrometric chart in Figure 5-12, one can use Equation (5-5) to calculate the water vapour content to be removed, as follows:

$$\boldsymbol{V_s} = \frac{\boldsymbol{G}}{\boldsymbol{\rho}.(\boldsymbol{x_i} - \boldsymbol{x_s})} \tag{5-5}$$

where

V_s =	Volume of supply air to remove contaminants	[m^3/h per person]
G =	Total moisture gains of a space	[g/s]
ρ =	Density of room air	[1.183kg/m^3]
x_i =	Moisture content of indoor air (23.5°C/50% RH)	[g/kg dry air]
x_s =	Moisture content of supply air (35°C/50% RH)	[g/kg dry air]

$$V_s = \frac{140g/h}{1.183kg/m^3.(\,(17.8 - 9)g/kg)} = 13.45m^3/h \text{ per person}$$

which is equivalent to 3.74 l/s per person

Thus, adding all three results together to determine personnel activity alone, would necessitate 0.13l/s for oxygen intake, 6.22 l/s for CO_2 removal and 3.74 l/s for water vapour evaporation from the skin during light/medium activity, which amounts to a total of 10.09l/s per person.

Therefore, depending on the activity as per Table 5-5 and Table 5-6, above, the fresh air required for ventilation due to personnel present in a building may vary by up to ± 60%.

The recently published standard EN 16798-1:19 [146] on indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics environmental indoor quality (IEQ), classifies non-residential buildings into four different categories as shown in Figure 5-7 below.

Category	**Level of expectation**
IEQ_{I}	High
IEQ_{II}	Medium
IEQ_{III}	Moderate
IEQ_{IV}	Low
NOTE In the tables only the category numbers are used without the IEQx symbol.	

Figure 5-7: categories of indoor environmental quality
taken from table 4 of EN 16798 [146]

The above categories are related to the level of expectations the non-adapted occupants fall under:

- **Category I** is a high level of expectation and is recommended for spaces occupied by susceptible and fragile persons with special needs such as disabled, sick, very young children and elderly persons.
- **Category II** is a normal level of expectation and should be used for new buildings and renovations.

- **Category III** is an acceptable, moderate level of expectation and may be used for existing buildings.
- **Category IV** is when values are outside the criteria for the above categories. This category should only be accepted for a limited part of the year.

As suggested in this standard, a reasonable level for general purpose applications would be “Medium”, while a higher level may be selected for occupants with special needs such as children, elderly, persons with disabilities, etc. A lower level will not provide any health risk but may decrease comfort.

Also, together with such categories, this EN 16798-1 standard gives the required internal environment requirements based on the Predicted Mean Vote with the percentage of dissatisfied persons (PMV-PPD) for indoor air quality in buildings, as given in EN ISO 7730 [122], and reproduced in Figure 5-8. For a medium category building, 7 l/s per person would give 20% of dissatisfaction. Such indices of dissatisfaction are based on non-adapted persons, which means they have just entered the room or zone or are heavily dependent on airconditioned air in their lifestyle.

Category	Expected Percentage Dissatisfied	Airflow per non-adapted person l/(s per person)
I	15	10
II	20	7
III	30	4
IV	40	2,5

Figure 5-8: Ventilation rates for non-adaptive adults with corresponding PPD for breathing and diluting emissions from body effluents

5.4.2 Pollutants due to buildings fabric or processes

The fourth and last source of pollution comes from the building’s fabric and/or adjacent processes, namely:

a) Equipment related to furniture and flooring which release volatile organic compounds (i.e. carbon-based compounds that quickly evaporate);

b) Technologies, i.e. HVAC, IT, etc.;
c) Animals;
d) Infiltration of outside pollutant sources such as,
   i. Traffic – CO, CO_2, NOX, etc.
   ii. Earth – radon released from the soil, which is dangerous in case of accumulation in spaces and prolonged exposure to it.

For such pollutants, the same standard EN 16798-1 [112] splits the four building categories into three classes according to the building pollution ratings based on the ALDREN project [148], which as per EPBD mandate documents the quality of the indoor environment in buildings undergoing deep energy renovation processes as highlighted below:

a) Very low polluting buildings;
b) Low polluting buildings;
c) Non-low polluting buildings.

For each of the above building pollution classifications, the ventilation rate for the four levels of air quality is given as a recommended airflow per square metre, as shown in Figure 5-9.

Category	**Very low polluting building, LPB-1 l/(s m²)**	**Low polluting building, LPB-2 l/(s m²)**	**Non low-polluting building, LPB-3 l/(s m²)**
I	0,5	1,0	2,0
II	0,35	0,7	1,4
III	**0,2**	**0,4**	**0,8**
IV	0,15	0,3	0,6

Figure 5-9: Design ventilation rates for diluting emissions in different types of buildings. source EN 16798-1 [146]

5.4.3 Calculation of total airflow required for adequate ventilation

The above procedures are applied to determine the ventilation flows for all non-residential categories, in order to determine the required ventilation flow for each of them.

In calculating these flows, one needs to take into consideration the guidance of the standard EN16798-1, whereby dimensioning of ventilation demand should consume the least energy for both summer and winter. Also, as seen in Table 5-7 below, the typical unit ventilation rates in l/s per m^2 of floor area for low polluting buildings with different occupation densities are given and these will be used in this study, when calculating the good practice benchmarks for various categorised buildings.

Table 5-7: Unit ventilation rates for low-polluting buildings of different occupation density

Type of Building Space	Occupation density m^2/persons	Category EN 16798-1	Low polluting building q_B l/(s.m^2)	Air flow per non-adapted person q_P l/s per person	Total design ventilation rate Q_{tot} l/(s.m^2)
Single Office	10.00	I	1.00	10.00	2.00
		II	0.70	7.00	1.40
		III	0.40	4.00	0.80
		IV	0.30	2.50	0.55
Landscaped office	14.29	I	1.00	10.00	1.70
		II	0.70	7.00	1.19
		III	0.40	4.00	0.68
		IV	0.30	2.50	0.48
Conference room	2.00	I	1.00	10.00	6.00
		II	0.70	7.00	4.20
		III	0.40	4.00	2.40
		IV	0.30	2.50	1.55
Classroom	2.00	I	1.00	10.00	6.00
		II	0.70	7.00	4.20
		III	0.40	4.00	2.40
		IV	0.30	2.50	1.55

Although the above airflow rates are based on the Predicted Mean Vote/Percentage of persons dissatisfied as PMV-PPD(EN ISO 7730) and also cover on the recently issued ventilation standard ASHRAE 62.1 [149], the values, as shown in Table 5-7, are more than triple those recommended by ASHRAE. This discrepancy is explained by Professor Bjarne W. Olesen in his paper on the philosophy behind the design of indoor environment criteria [150]. In ASHRAE the predicted mean vote (PMV-PPD) is taken by persons, who within 15 minutes have already adapted to the environment.

On the other hand, the ventilation rates given in EN16798-1, as specified for the four categories of indoor air quality, are based on the prediction that persons have just entered the rooms, are non-adaptive to the environment, and who find the air quality unacceptable.

The UK building regulations *Approved Document B2, Fire safety in Buildings other than Dwelling Houses* [151] provides a list of occupation density or space load factors for various types of buildings, whereby the occupation density of a room, storey, building or part of a building is defined as :

- The maximum number of persons it is designed to hold; or
- The number is calculated by dividing the area of room or storey(s) (m^2) by a floor space factor (m^2 per person), such as given in Table D1, shown in Figure 5-10 below.

Table D1 Floor space factors[1]

Type of accommodation[2][3]	Floor space factor (m^2/person)
1. Standing spectator areas, bar areas (within 2m of serving point), similar refreshment areas	0.3
2. Amusement arcade, assembly hall (including a general purpose place of assembly), bingo hall, club, crush hall, dance floor or hall, venue for pop concerts and similar events and bar areas without fixed seating	0.5
3. Concourse or queuing area[4]	0.7
4. Committee room, common room, conference room, dining room, licensed betting office (public area), lounge or bar (other than in (1) above), meeting room, reading room, restaurant, staff room or waiting room[5]	1.0
5. Exhibition hall or studio (film, radio, television, recording)	1.5
6. Skating rink	2.0
7. Shop sales area[6]	2.0
8. Art gallery, dormitory, factory production area, museum or workshop	5.0
9. Office	6.0
10. Shop sales area[7]	7.0
11. Kitchen or library	7.0
12. Bedroom or study-bedroom	8.0
13. Bed-sitting room, billiards or snooker room or hall	10.0
14. Storage and warehousing	30.0
15. Car park	Two persons per parking space

NOTES:

1. As an alternative to using the values in the table, the floor space factor may be determined by reference to actual data taken from similar premises. Where appropriate, the data should reflect the average occupant density at a peak trading time of year.
2. Where accommodation is not directly covered by the descriptions given, a reasonable value based on a similar use may be selected.

Figure 5-10: Table D1 for floor space factors as given in Document B2 [151]

By using these space load factors, the ideal ventilation rate per unit area for various types of buildings is calculated later in this chapter.

5.5 Air moisture content in space cooling processes

Humid air is a mixture of dry air and water vapour. From air property data, one can assume that both dry air and water vapour obey the ideal gas law. It is therefore rational to assume that humid air behaves as an ideal gas mixture. The moisture content of humid air, W, is defined as the mass of water vapour contained in 1 kg of dry air. Also, generally the moisture content is sometimes referred to as specific humidity, absolute humidity or humidity ratio.

Thus

$$\boldsymbol{W} = \frac{\boldsymbol{m_s}}{\boldsymbol{m_a}} \textbf{kg of water vapour/kg of dry air} \qquad (5\text{-}6)$$

Where:

W	=	Mass of water vapour in dry air	Kg/kg of dry air
m_s	=	Mass of water vapour	Kg
m_a	=	Mass of dry air	Kg

From the ideal gas law [105]

For dry air (suffix a)

$$\mathbf{P_a\,V_a = m_a\,R_a\,T_a \;\rightarrow m_a = \frac{P_a\,V_a}{R_a\,T_a}}$$

For water vapour or steam (suffix s)

$$\mathbf{P_s\,V_s = m_s\,R_s T_s \;\rightarrow m_s = \frac{P_s\,V_s}{R_s\,T_s}}$$

Where:

P	=	Pressure	Pa
V	=	Volume of air	m^3
m	=	mass	Kg
R	=	A constant of proportionality known as the Specific Gas Constant	J kg^{-1} K^{-1}
T	=	Absolute temperature of air	K

However, for the mixture

$V_s = V_a$ and $T_s = T_a$

therefore, substitution in Equation (5-6) and inserting the molecular weight for R_s and R_a gives

$$\boldsymbol{W} = \frac{\boldsymbol{R_a P_s}}{\boldsymbol{R_s P_a}} = \frac{\mathbf{18.02}\, \boldsymbol{P_s}}{\mathbf{28.97}\, \boldsymbol{P_a}} = \mathbf{0.622}\, \frac{\boldsymbol{P_s}}{\boldsymbol{P_a}} \quad \textbf{kg of water vapour/kg of dry air} \qquad (5\text{-}7)$$

From Dalton's law of partial pressures [105]:

P_{atm} (atmosphere) = $P_a + P_s$

Then Equation (5-7) can be written as

$$\boldsymbol{W} = \mathbf{0.622}\, \frac{\boldsymbol{P_s}}{\boldsymbol{P_{atm}} - \boldsymbol{P_s}} \quad \textbf{kg of water vapour/kg of dry air} \qquad (5\text{-}8)$$

The moisture content corresponding to the saturation vapour pressure, known as the saturation moisture content, W_{ss}, can be calculated from Equation (5-8) by substituting P_s for the saturated water vapour pressure, P_{ss} The saturation moisture content can be plotted against temperature on a psychrometric chart, as shown in Figure 5-11 to give the percentage saturation.

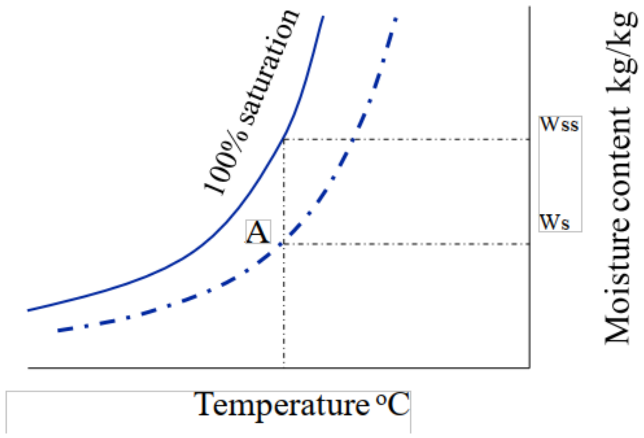


Figure 5-11: Moisture content on the psychrometric chart

Superimposition of the properties of dry air and water vapour gives rise to what is known as the Psychrometric Equation i.e. Equation (5-9), which is mostly empirical but can be produced accurately in tables or in charts.

$$P_s = P_{ss'} - P_{atm}\,\mathrm{A}\,[t - t'] \qquad (5\text{-}9)$$

Where

t is the dry bulb temperature

t' is the wet-bulb temperature, and

A is a constant

$$A = 7.99 \times 10^{-4}\ K^{-1}\ for\ t' \geq 0^0 C$$
$$A = 7.20 \times 10^{-4}\ K^{-1}\ for\ t' < 0^0 C$$

Generally, the properties of humid air are given in tables which for a given dry-bulb temperature and atmospheric pressure, (usually 1013.25 mbar) display other property values. It is important to note that the moisture content, the specific enthalpy and the specific volume are given per kg of dry air. Also, at 100% saturation, the relative humidity is 100%, and all the temperatures (dry bulb, wet bulb and dewpoint) are equal. The vapour pressure at this condition is the saturation vapour pressure.

Property values which are not specified in the tables can be determined with reasonable accuracy, by performing linear interpolation between the two closest values specified.

The psychrometric tables are useful in accurately determining the properties of humid air at a given state point but provide little information on how the properties change during a process. This information is provided by the psychrometric chart, which is a graphical representation of the critical properties of humid air.

The chart provides a picture of how the state of moist air alters as an air-conditioning process takes place, or a physical process occurs. A typical psychrometric chart with Summer cooling process is shown schematically in Figure 5-12.

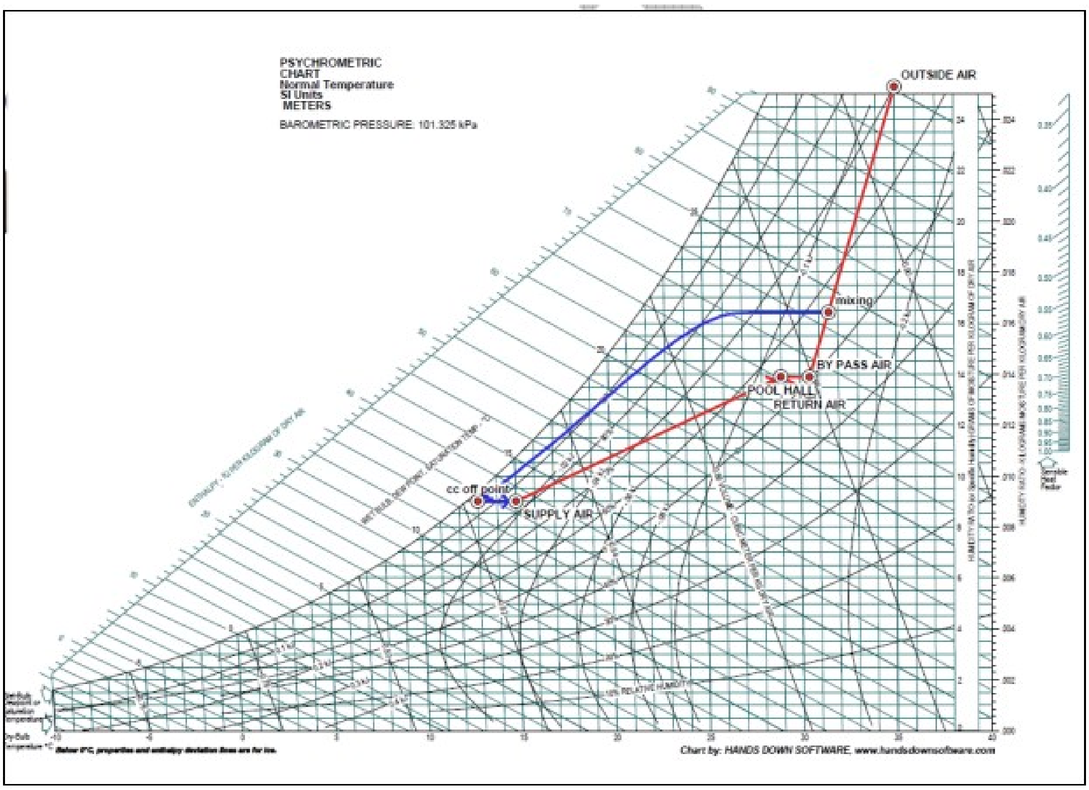


Figure 5-12: Psychrometric Chart with a summer cooling flow process [adapted from Hands Down software] [152]

Nowadays, such charts are also provided digitally with special application software. Whether manual or digital, one can find all properties of the moist air condition processes, if any two parameters are known i.e. dry bulb temperature, wet bulb temperature, dew point, relative humidity, absolute humidity, enthalpy, density, specific volume or pressure.

However, the hourly meteorological data used in this thesis includes date, time, dry bulb temperature (T); dew point temperature (T_d), relative humidity (RH) and atmospheric presume (P_{at}). In such circumstances to apply Equation (5-8) to calculate the outside air moisture content, it is necessary to first know its associated vapour pressure (p_w).

Furthermore, moist air vapour pressure is proportional to the moisture content, which from the psychrometric chart is the intersection at 100% saturation, i.e. the dew-point temperature. Referring to the ASHRAE 2017 *Fundamentals Handbook* on psychrometry for humid air with a dew-point between 0 and 93°C, the water vapour partial pressure (p_w) can be calculated using the dew-point temperature as given by Equation (5-10) [153] .

$$\boldsymbol{T_d = C_{14} + C_{15}\alpha + C_{16}\alpha^2 + C_{17}\alpha^3 + C_{18}(p_w)^{0.1984}} \qquad (5\text{-}10)$$

where

T_d= dew-point temperature, °C

$\boldsymbol{\alpha}$ = ln p_w

p_w = Water vapour partial pressure, kPa

C_{14} = 6.54

C_{15} = 14.526

C_{16} = 0.7389

C_{17} = 0.09486

C_{18} = 0.4569

Equation (5-10) is rather tedious to solve for a long list of daily hourly data for several years on a long excel sheet. However, work done in 1985 by W. Wagner and A. Pruß: in their paper *The IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use* [154], simplified this to Equation (5-11) giving :

$$T_d = \frac{T_n}{\frac{m}{10_{log}\left(\frac{p_w}{A}\right)}} - 1 \qquad (5\text{-}11)$$

Where

A, m and T_n are constants as shown in Table 5-8 below.

Table 5-8: Constants in Wagner's equation for various temperatures ranges

A	M	T_n	Error	Temperature range
6.116441	**7.591386**	**240.7263**	**0.083%**	**-20 to 50 °C**
6.004918	7.337936	229.3975	0.017%	+50 to 100 °C
5.85648	7.27731	225.1033	0.003%	+100 to 150 °C
6.002859	7.290361	227.1704	0.007%	+150 to 200 °C
9.980622	7.388931	263.1239	0.395%	+200 to 350 °C
6.089613	7.33502	230.3921	0.368%	0 to 200 °C

Rearranging Equation (5-11) and using constants for temperature range from -20 to 50°C from Table 5-8 gives Equation (5-12) below :

$$p_w(\mathbf{mbar}) = \mathbf{A}\,\mathbf{10}^{\frac{m}{\left\{\left(\frac{T_n}{T_d}\right) - 1\right\}}} \qquad (5\text{-}12)$$

As a test for the validity of Equation (5-12) two points P1 and P2 were plotted on a digital psychrometric chart namely at 23°C, 50% RH and 35°C, 50% RH each with a dew-point of 12.5 and 23°C respectively, as shown in Figure 5-13.

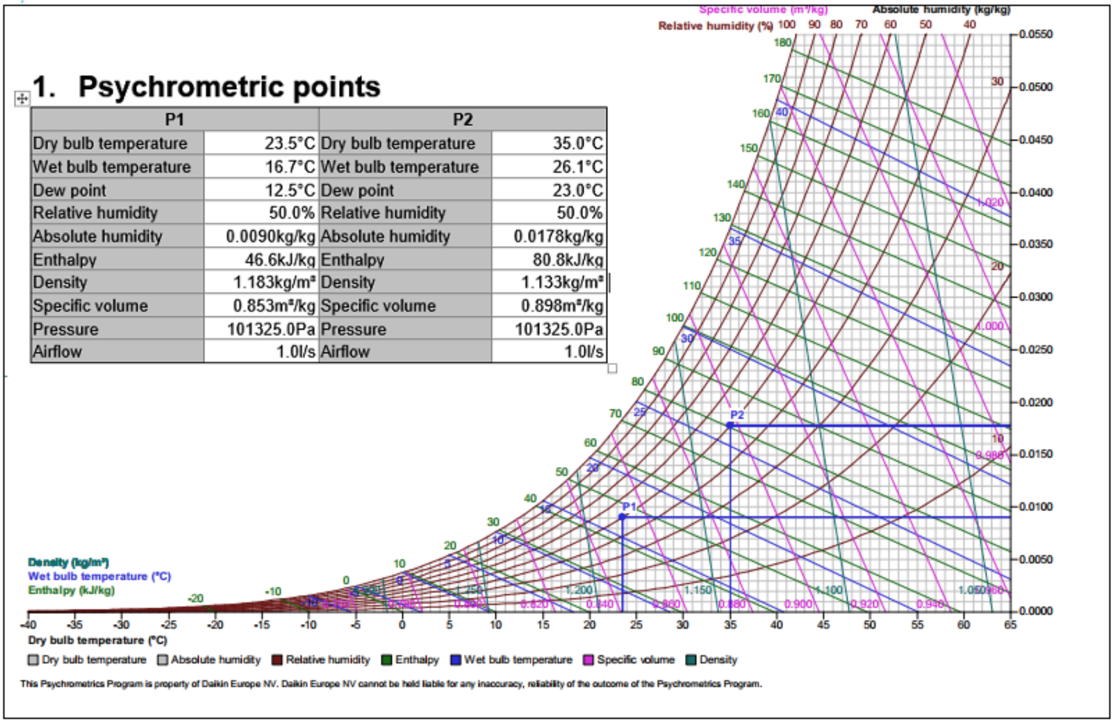


Figure 5-13: Two comparable data points on the psychrometric chart [155]

When these results were compared to the calculations’ outputs of equation (5-12), the percentage error was found to be minimal, as shown in Table 5-9.

Table 5-9: Difference between data values from equation (5-12) and digital psychrometric chart

Dry Bulb Temp (T)	Dew Point (Td)	Relative Humidity	Atmospheric Pressure (Pat)	Vapour Pressure (Pw)	Moisture content (W_o) kg/ kg of dry air		
[°C]	[°C]	[%]	mbar	mbar	From Equation	From Chart	Difference
23.50	12.50	50	1025	14.50	0.0089	0.0090	-0.0001
35.00	23.00	50	1025	28.09	0.0175	0.0178	-0.0003

As such Equations (5-8) and (5-12) could be applied to the available hourly meteorological data to find the change in moisture content between the outdoor and indoor air. This makes it possible to calculate the specific unit energy required to meet the latent ventilation load with sufficient level of accuracy for all non-residential clusters.

5.5.1 Calculation of moisture content of indoor air

The next stage is to calculate the thermal indoor condition, using dimensions criteria of Table B.1 of the same standard EN16798-1 for a PPD-PMV (EN ISO 7730) [122], for each of the 29 categorised benchmark buildings shown in Table 2-15 of this thesis, according to the category of use as shown in Figure 5-14 below.

Category	Thermal state of the body as a whole	
	Predicted Percentage of Dissatisfied PPD %	Predicted Mean Vote PMV
I	< 6	−0,2 < PMV < + 0,2
II	< 10	−0,5 < PMV < + 0,5
III	< 15	−0,7 < PMV < + 0,7
IV	< 25	−1,0 < PMV < + 1,0

Figure 5-14: Default categories for the design of mechanically heated and cooled buildings [146]

For such, benchmark buildings, room internal data taken from table 1.5 of CIBSE *Guide A* [123], gives general guidance and recommended comfort criteria for specific building types, based on professional experience and judgement, for suitable Winter and Summer temperatures all based on the predicted percentage of persons dissatisfied, as a function of predicted mean vote (PMV), as shown in Figure 5-15 for various types of buildings. As an example, for office category 1 the internal temperature range from this CIBSE table varies from 22 to 25°C in Summer so an internal average temperature of 23.5°C with 50% RH is adequate, for which psychrometric details are given in Table 5-10.

Building/room type	Customary winter operative temperatures for stated activity and clothing levels*			Customary summer operative temperatures (air conditioned buildings†) for stated activit and clothing levels*		
	Temp. / °C	Activity / met	Clothing / clo	Temp. / °C	Activity / met	Clothing / clo
Ice rinks	12	—	—	—	—	—
Laundries:						
— commercial	16–19	1.8	0.9	—[19]	—	—
— launderettes	16–18	1.6	1.2	20–25	1.4	0.6
Law courts	19–21	1.4	1.0	21–25	1.3	0.6
Libraries:						
— lending/reference areas[28]	19–21	1.4	1.0	21–25	1.3	0.6
— reading rooms	22–23	1.1	1.0	24–25	1.1	0.6
— store rooms	15	—	—	—	—	—
Museums and art galleries:						
— display[25]	19–21	1.4	1.0	21–25	1.3	0.6
— storage[25]	19–21	1.4	1.0	21–25	1.3	0.6
Offices:						
— board room, large conference room	21–23	1.2	0.9	22–25	1.2	0.7
— general, small conference room, executive office	21–23	1.2	0.9	22–25	1.2	0.7
— open-plan	21–23	1.2	0.9	22–25	1.2	0.7
Places of public assembly:						
— concert hall, theatre[27]	21–23	1.0	1.0	24–25	1.1	0.6
— cinema	21–23	1.0	1.0	24–25	1.1	0.6
— changing/dressing rooms	21–23	—	—	22–25	1.4	0.4
— circulation spaces	13–20[1]	1.8	1.0	21–25[1]	1.8	0.6
— foyers[28]	13–20[1]	1.8	1.0	21–25[1]	1.8	0.6
— multi-purpose halls[29]	—	—	—	—	—	—
Prison cells	19–21	1.0	1.5	21–25	1.0	1.1
Railway/coach stations:						
— concourse (no seats)	12–19[1]	1.8	1.2	21–25[1]	1.8	0.6
— ticket office	18–20	1.4	1.2	21–25	1.3	0.6
— waiting room	21–22	1.1	1.2	24–25	1.1	0.6
Restaurants/dining rooms	21–23	1.1	1.0	24–25	1.1	0.6
— night club, public house, cafeteria	19–21	1.4	1.0	21–25	1.3	0.6

Figure 5-15: : Part of CIBSE Table A 1.5 for recommended internal comfort criteria [123]

Therefore, for each of the 29 categorised buildings, the internal conditions are recorded, and the internal moisture content is calculated from the psychrometric chart, as shown in Table 5-10 for building category Type 1.

Table 5-10: Example using building category Type 1 internal conditions

Year		2016	
Building category		1	
Type		General office	
Internal room conditions			
	Temperature (T_i)	23.5	⁰C
	RH	50	%
	Moisture content (W_i)	0.009	kg/kg of dry air
	Air density	0.001183	kg/litre of air

Furthermore, the daily operating schedule for each of the 29 categorised buildings shown in Table 2-15 is recorded for the total annual allocated hours, as given in the UK benchmarks. These were rescheduled to reflect Malta's particular daily and weekly local building operating time, which are shown in Table 5-11 for selected benchmarked buildings ie offices, hotel, sports centre, schools, hospitals and storage facilities columns F to I.

.

Table 5-11: Part of the 29 categorised buildings with internal conditions and operation schedule

A	B	C	D	E	F	G	H	I	J	K
	Name and description	Allocation guides			Operating time				Internal condition	
Cat	Name	Space usage	Operational schedule	Reference hours per year	From	To	Days	Total hrs	DB ^{o}C	RH %
1	**General office**	Mainly by employees, for sedentary desk-based activities. Includes meeting and conference facilities.	Weekdays and early evenings	2040	8	17	5	9 hrs weekdays	23.5	50
9	**Hotel**	Primarily the provision of short-term accommodation and hygiene facilities	Primarily used in evenings and early morning	6560	14	7am	7	All days	24	50
14	**Dry sports and leisure facility**	Dry sports and club house buildings: Combined leisure centre include pool etc.	Ranges from occasional use to daily and evening	2754	10	20	7	All days	24	55
17	**Schools and seasonal public buildings**	Teaching and community activities	Weekday use for part of the year	1400	8	14	5	9 hrs weekdays	23.5	50
20	**Hospital: Clinical and research**	Mainly space for medical care with 24-hour accommodation for patients, with associated operating theatres, laboratories, offices and workshops	Continuous use by the majority of the facility	8760	0	24	7	All days	24	50
28	**Storage facility**	Storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2040	8	17	5	9 hrs weekdays	23.5	50

The hourly recorded meteorological data for years the 2016, 2017 and 2018 is tabulated in an excel worksheet for each categorised building, in date order and filtered such that the latent load is only calculated when the following conditions are met:

a) When equipment is in operation as per schedule according to data in
b) for that particular category. An example for 2016 for category 1 office type 1 is shown in Table 5-12.
c) When the outside temperature is equal or above the cooling base temperature of 18.5˚C.

Results are shown in Table 5-12 below, whereby:

i. Column A illustrates days of operation during the week
ii. Column D illustrates the daily time of operation
iii. Column E illustrates only outside temperature ≥ 18.5 ^{0}C
iv. Column I data returns the value of outdoor air vapour pressure as per Equation (5-12)
v. Column J calculates and returns the outdoor air moisture content data as per Equation (5-8)
vi. Column K calculates and only returns positive values of the difference in moisture content multiplied by the latent heat of water (i.e. h_{fg} @ 2525 kJ/kg) and divided by the room air density to give the energy use intensity in kWh per litre of ventilation air.

Table 5-12: 2016 adjusted meteorological data for 2016 for an example office (Cat 1) operating schedule with latent load calculations during cooling

Column A filtered for weekly operating schedule

Column D filtrerei for daily operating schedule

Comun E filtrerei to return values above or equal to cooling base temperature

Column I calculates vapour pressure as per Eq 5-12

Column J calculates outside air moisture content as pe Eq 5-8

A	B	C	D	E	F	G	H	I	J	K
Day	Month	Date	Time UTC	Dry Bulb Temp [°C]	Dew Point (Td) [°C]	Relative Humidity [%]	Atmospheric Pressure (Pat) mBar	Vapour Pressure (Pw) mbar	Moisture content (Wo) kg/ kg of dry air	L_{atent} kWh per litre of air
Tues	Jan	5	14:00	19.50	14	71	1007	15.99	0.0100	0.0022
Tues	Jan	5	15:00	18.50	14	75	1007	15.99	0.0100	0.0022
Sun	Feb	14	14:00	18.50	15	80	1004	17.05	0.0107	0.0044
Sun	Feb	28	14:00	19.00	14	71	1000	15.47	0.0098	0.0014
Thurs.	Apr	1	14:00	19.00	14	73	1014	15.99	0.0100	0.0020
Thurs.	Apr	1	15:00	18.50	14	75	1014	15.99	0.0100	0.0020
Tues	Apr	6	14:00	19.00	14	73	1006	15.99	0.0100	0.0022
Wed	Apr	7	14:00	19.50	14	71	998	15.99	0.0101	0.0025
Wed	Apr	14	06:00	18.50	14	73	1011	15.47	0.0097	0.0011
Wed	Apr	14	14:00	21.50	13	59	1011	14.98	0.0094	0.0002
To Continue till end of year										
Thurs.	Nov	25	20:00	19.00	19	100	1013	21.97	0.0138	0.0135
Thurs.	Nov	25	21:00	19.00	18	94	1013	20.64	0.0129	0.0110
Fri	Nov	26	07:00	18.50	18	94	1014	20.00	0.0125	0.0097
Fri	Nov	26	14:00	19.50	17	86	1013	19.37	0.0121	0.0085
Fri	Nov	26	15:00	19.00	17	86	1013	18.77	0.0117	0.0074
Sat	Nov	27	14:00	20.00	14	68	1009	15.99	0.0100	0.0021
Sat	Nov	27	15:00	19.00	14	71	1009	15.47	0.0097	0.0012
Mon	Dec	6	07:00	18.50	14	73	1024	15.47	0.0095	0.0007
Mon	Dec	6	14:00	19.00	14	71	1022	15.47	0.0096	0.0008
Fri	Dec	10	14:00	18.50	14	75	1026	15.99	0.0098	0.0016
Total for year to benchmark category sheet										**13.48**

The subtotal of the unit-specific latent energy for this year is then transferred and inputted in Column L of the latent load summary worksheet, as partly expressed in Table 5-13 below for selected buildings.

This was repeated for all 29 category buildings and for all three years. The three-year average for columns L, M and N was calculated and placed in column O, to give the unit latent load per litre of ventilation airflow.

Table 5-13: Typical unit latent energy gain in kWh per litre for sample categories buildings for years 2016 to 2018

A	B	L	M	N	0
Name and description		Yearly latent load due to ventilation on cooling (kWh/ litre of ventilation air			
Cat	Name	2016	2017	2018	Yearly average
1	General office	13.48	10.79	17.47	13.91
9	Hotel	35.28	34.65	42.45	37.46
14	Dry sports and leisure facility	14.29	13.77	17.92	15.33
17	Schools and seasonal public buildings	10.89	8.69	10.74	10.11
20	Hospital: clinical and research	45.28	40.35	54.34	46.66
28	Storage facility	13.48	10.79	17.47	13.91

5.5.2 Latent energy intensity absorbed per unit area

As explained in Section 5.4 each of the 29 building categories is classified according to the four classes, as listed in standard EN16798 and their occupation densities are also identified, as shown in columns P and Q of Table 5-14.

This enabled the calculation of the required airflow for personnel and *low polluting building*, as well as the total categorised unit latent load in kWh/m^2 in column U, as shown in Table 5-14.

Table 5-14 gives a full picture of the whole results of latent heat for cooling, for the selected sample categories. A full schedule for all the 29 categories is given in Appendix A.

Table 5-14: Part summary of cooling specific latent load for benchmarked buildings

A	B	C	D	E	F	G	H	I	J	K	L	M	N	0	P	Q	R	S	T	U
Name and description		Allocation guides			Operating time				Internal condition		Yearly latent load due to ventilation on cooling (kWh/ litre of ventilation air)				EN 16798	Floor space factors	Air flow per non-adapted person	Low polluting building	Total design ventilation rate	Total Q latent
Cat	Name	Space use	Operational schedule	Reference hours per year	From	To	Days	Total hrs	DB ºC	RH %	2016	2017	2018	Yearly average	Cat	m^2 per person	l/s per person	l/(s.Ym^2)	l/(s.m^2)	kWh/m^2
1	General office	Mainly by employees, for sedentary desk-based activities. Includes meeting and conference facilities.	Weekdays and early evenings	2040	8	17	5	9 hrs weekdays	23.5	50	13.48	10.79	17.47	13.91	III	6	4	0.4	1.07	**14.84**
9	Hotel	Primarily the provision of short-term accommodation and hygiene facilities	Primarily used in evenings and early morning	6560	14	7am	7	All days	24	50	35.28	34.65	42.45	37.46	III	8	4	0.4	0.90	**33.71**
14	Dry sports and leisure facility	Dry sports and club house buildings: for a combined leisure centre include pool etc.	Ranges from occasional use to daily and evening	2754	10	20	7	All days	24	55	14.29	13.77	17.92	15.33	III	4	4	0.4	1.40	**21.46**
17	Schools and seasonal public buildings	Teaching and community activities	Weekday usage for part of the year	1400	8	14	5	9 hrs weekdays	23.5	50	10.89	8.69	10.74	10.11	III	5	4	0.4	1.20	**12.13**
20	Hospital: Clinical and research	Mainly space for medical care with 24-hour accommodation for patients, with associated operating theatres, laboratories, offices and workshops	Continuous for the majority of the facility	8760	0	24	7	All days	24	50	45.28	40.35	54.34	46.66	I	8	10	1	2.25	**104.99**
28	Storage facility	Storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2040	8	17	5	9 hrs weekdays	23.5	50	13.48	10.79	17.47	13.91	III	30	4	0.4	0.53	**7.42**

5.6 Energy benchmarks for Malta

For the UK benchmarks presented in Table 2-15 of this thesis, the EUI values for each categorised building is separated for electricity and fossil fuel at end users' point in kWh/m^2.yr, with heating more heavily sourced from fossil fuels. This is normal for a predominantly heating load country. While for electricity, this includes all the engineering services one can expect to find in such categories of buildings such as HVAC, domestic hot and cold water, lighting, IT, firefighting, etc.

5.6.1 Weather-dependent and independent Energy Use Intensities (EUIs)

CIBSE TM46 [61] guide gives the percentage of electricity and fossil fuel thermal energy used pro-rated to the UK weather dependant of 2021 degree-days. These are partly reproduced for the selected categorised buildings in Table 5-15 below.

However, Malta being a predominantly cooling load country, whereby electricity rather than direct use of fossil fuel is used for powering cooling equipment, it is not justified to have separate benchmarks for electricity and for other fossil fuel sources. In other words, only one total EUI will be provided.

Table 5-15: UK benchmarks with separate unit consumption for electricity and fossil fuel and the percentages associated with 2021-degree days for sample of categorised buildings

A	B	L	M	N	O	P	Q
Name and description		Energy benchmarks for UK			Weather adjustment for UK		
Cat	Name	Electricity typical benchmark (kWh/m².yr)	Fossil-thermal typical benchmark (kWh/m²yr)	Total (kWh/m².yr)	Percent of electricity benchmark pro-rated to degree-days	Percent of fossil-thermal benchmark pro-rated to degree-days	Total for weather adjustment of 2021 DD
1	General office	95	120	**215**	0%	55%	66.00
9	Hotel	105	330	**435**	0%	45%	148.50
14	Dry sports and leisure facility	95	330	**425**	0%	55%	181.50
17	Schools and seasonal public buildings	36	105	**141**	0%	55%	57.75
20	Hospital; clinical and research	90	420	**510**	0%	55%	231.00
28	Storage facility	35	160	**195**	0%	70%	112.00

Figure 5-16 shows in chart form all the UK 29 categories of good practice benchmarks for non-residential buildings separated between the EUIs which are weather-independent (red) and those which are weather-dependent (orange). The weather-dependent component is attributed to space heating and cooling for indoor thermal comfort with heating being more pronounced among EU Member States classified in Zone B due to their cold Winter and mild Summer climate [19]. These almost cover one third of the total EUIs consumed for the UK.

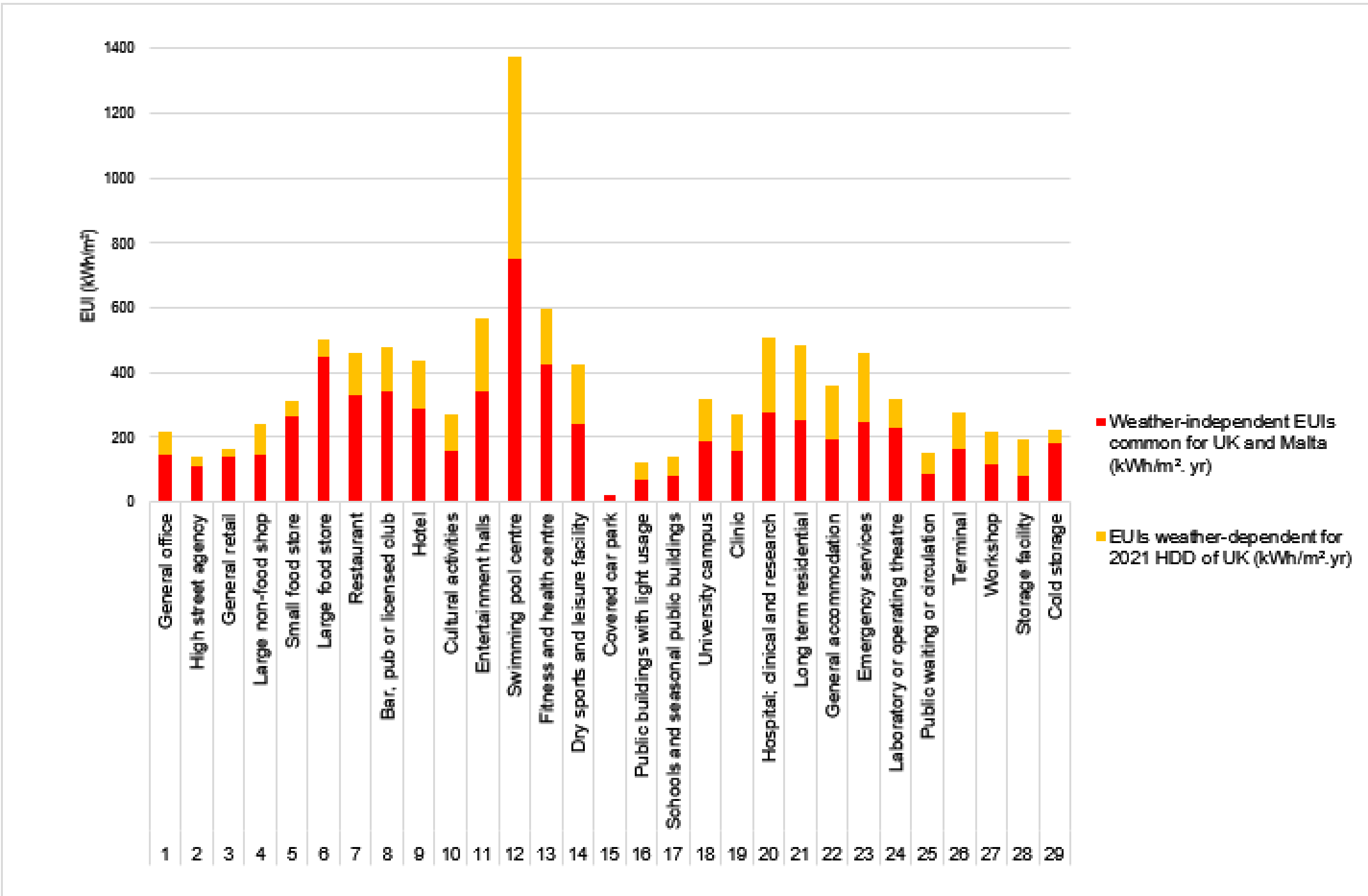


Figure 5-16: UK weather-independent and weather-dependent EUIs for non-residential buildings benchmarks

Another problem associated with predominantly cooling load countries is, as highlighted in ASHRAE Fundamental 2017 Handbook [105] in chapter nineteen *Energy Estimating And Modelling Methods* is that, in energy modelling the balance or base temperature for which no cooling or heating is required inside the building is taken as 15.5^{o}C. However, during cooling to make up for the period when the building is cooled by natural ventilation as shown in Figure 2.17 this base temperature is shifted to 18.5^{o}C.

Also air-conditioning systems are generally switched off during uncopied periods. Thus, cooling degree-hours better represents the period when the equipment is running than the cooling degree-days. In the degree day method, it assumes uninterrupted equipment operation as long as there is cooling or heating. Hence for each building category, the cooling degree days had to be filtered for the daily and weekly schedule of operation, according to its class as shown in Table 5-16.

Table 5-16: 2016 calculations of Malta degree days for cooling only when plant is in operation

Degree Days Calculations

Base Temperatures			Degree Days		
Heating	15.5	°C	Heating	360	HDD
Cooling	18.5	°C	Cooling	501	CDD
			Total	861	TDD

Filter for day and time of operation on cooling

Filter for outside temperature above base 18.5°C

Day	Month	Date	Time UTC	Dry Bulb Temp [°C]	Dew Point (Td) [°C]	Relative Humidity [%]	Atmospheric Pressure (Pa) mBar	Heating Degree Days	Cooling Degree Days
Mon	Mar	**20**	**11:00**	18.50	4	37	1016	-3	0
Mon	Mar	**20**	**12:00**	20.00	-1	25	1015	-5	2
Mon	Mar	**20**	**13:00**	20.00	1	27	1014	-5	2
Mon	Mar	**20**	**14:00**	20.00	5	36	1014	-5	2
Mon	Mar	**20**	**15:00**	18.50	7	46	1014	-3	0
Mon	Mar	**27**	**12:00**	18.50	11	62	1018	-3	0
To continue till end of year									
Wed	**Dec**	**13**	**08:00**	19.00	15	78	1023	-4	1
Wed	**Dec**	**13**	**09:00**	19.00	15	78	1023	-4	1
Wed	**Dec**	**13**	**10:00**	19.50	14	71	1023	-4	1
Wed	**Dec**	**13**	**11:00**	20.00	13	64	1022	-5	2
Wed	**Dec**	**13**	**12:00**	20.00	12	60	1022	-5	2
Wed	**Dec**	**13**	**13:00**	20.00	11	56	1021	-5	2
Wed	**Dec**	**13**	**14:00**	19.00	11	60	1021	-4	1
Total Cooling degree days when plant is in operation.									501

This was repeated for the two 2010 and 2017and averaged as shown in Table 5-17, column O. The UK weather-dependant EUIs as given in TM46 and reproduced in Table 5-15, were transferred to column P of Table 5-17, and multiplied by factor of average calculated Malta degree-days divided by the 2021 degree-days for UK, and the result inputted in column Q. This gave the weather-dependant EUI for Malta for that particular category. This was repeated for all categories as shown Table 5-18 for the chosen sample buildings. A full version of Table 5-18 with all categorised benchmark buildings is given in Appendix B.

Table 5-17: Harmonising UK weather dependent EUIs to Malta with total degree-days

A	B	C	D	E	F	G	H	I	L	M	N	0	P	Q
Name and description		Allocation guides			operating time				Total yearly DD for heating & cooling. Cooling DD harmonised during operation of main plant				Total UK EUIs for weather adjustment on 2021 DD	Malta EUIs DD weather adjusted
Cat	Name	Space usage	Operational schedule	Reference hours per year	From	to	Days	total hrs	2010	2016	2017	3 yearly average	(kWh/m².yr)	(kWh/m².yr)
1	General office	Mainly by employees, for sedentary desk-based activities. Includes meeting and conference facilities.	Weekdays and early evenings	2040	8	17	5	9 hrs weekdays	714	861	776	784	66.00	25.60
9	Hotel	Primarily the provision of short-term accommodation and hygiene facilities	Primarily used in evenings and early morning	6560	14pm	7am	7	all days	714	1114	847	892	148.50	65.51
14	Dry sports and leisure facility	Dry sports and club house buildings — for a combined leisure centre include pool etc.	Ranges from occasional use to daily and evening	2754	10	20	7	all days	1135	1047	788	990	181.50	88.89
17	Schools and seasonal public buildings	Teaching and community activities	Weekday usage for part of the year	1400	8	14	5	9 hrs weekdays	587	883	759	743	57.75	21.23
20	Hospital; clinical and research	Mainly space for medical care with 24-hour accommodation for patients, with associated operating theatres, laboratories, offices and workshops	Continuous for the majority of the facility	8760	0	24	7	all days	1297	1473	1332	1367	231.00	156.28
28	Storage facility	Storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2040	8	17	5	9 hrs weekdays	714	861	776	784	112.00	43.44

Table 5-18 follows on the two previous tables, i.e. Table 5-14 for Malta latent load ventilation as calculated in section 5.5.2 and Table 5-17, for the EUIs weather-dependent. Their categorised totals were inputted in columns R and S, respectively for the sample benchmarks.

Finally, the benchmark for Malta is given in column U, which is found by adding the net energy-independent component of the UK to the energy-dependent component of Malta. Table 5-19 shows the full table for good practice benchmarking non-residential buildings in Malta for categories. Another version of this table in A3 format is given in Appendix C.

Table 5-18: Calculated Benchmarks for non-residential buildings in Malta for selected categories

A	B	L	M	N	O	P	Q	R	S	T	U
Name and description		Energy benchmarks for UK			Weather adjustment			Weather adjusted for Malta (kWh/m^2)			Benchmark for Malta
Cat	Name	Electricity typical benchmark ($kWh/m^2 \cdot yr$)	Fossil-thermal typical benchmark ($kWh/m^2 .yr$)	Total ($kWh/m^2 .yr$)	Percent of electricity benchmark pro-rated to degree-days	Percent of fossil-thermal benchmark pro-rated to degree-days	Total for weather adjustment of 2021 DD	Adjusted Malta TDD when cooling plant is on (kWh/m^2)	L_{atent} due to ventilation on cooling ($kWh/m^2 .yr$)	Total energy due to weather ($kWh/m^2 .yr$)	Total Energy usage per unit area ($kWh/m^2 .yr$)
1	General office	95	120	**215**	0%	55%	66.00	25.60	14.84	40.44	**189**
9	Hotel	105	330	**435**	0%	45%	148.50	65.51	33.71	99.23	**386**
14	Dry sports and leisure facility	95	330	**425**	0%	55%	181.50	88.89	21.46	110.35	**354**
17	Schools and seasonal public buildings	36	105	**141**	0%	55%	57.75	21.23	12.13	33.36	**117**
20	Hospital; clinical and research	90	420	**510**	0%	55%	231.00	156.28	104.99	261.27	**540**

Table 5-19: Adjusted non-residential energy use benchmarks for non-residential buildings in Malta

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Name and description			**Allocation guides**				**Further category details**				**Energy benchmarks for UK**			**Weather adjustment for UK**			**Weather adjusted for Malta (kW·h/m^2.yr)**			**Benchmark for Malta**
Cat	**Name**	**Brief description**	**Space usage**	**Operational schedule**	**Reference hours per year**	**Distinguishing features**	**Services included**	**May be part of mixed use with areas below**	**Summary of allowable special energy uses**	**Representative buildings**	**Electricity typical benchmark (kW·h/m^2.yr)**	**Fossil-thermal typical benchmark (kW·h/m^{2}yr)**	**Total (kW·h/m^2.yr)**	**Percent of electricity benchmark pro-rated to degree-days**	**Percent of fossil-thermal benchmark pro-rated to degree-days**	**Total for weather adjustment of 2021 DD**	**Adjusted Malta TDD when cooling plant is on (kW·h/m^2.yr)**	**Q_{latent} due to ventilation on cooling (kW·h/m^2.yr)**	**Total energy due to weather (kW·h/m^2/yr)**	**Total Energy usage per unit area (kW·h/m^2.yr)**
1	**General office**	General office and commercial working areas	Mainly by employees, for sedentary desk-based activities. Includes meeting and conference facilities.	Weekdays and early evenings	2040	Relative uniformity of occupancy, density, conditions, schedule and appliances	Heating, lighting, cooling, employee appliances, standard IT, basic tea room	Covered car park, staff restaurant	Regional server room, trading floor	General office benchmark category for all offices whether air conditioned or not, Town Halls, architects, various business services that do not include retail functions	95	120	**215**	0%	55%	66.00	25.60	14.84	40.44	**189**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Name and description			Allocation guides				Further category details				Energy benchmarks for UK			Weather adjustment for UK			Weather adjusted for Malta (kW·h/m².yr)			Bench mark for Malta
2	**High street agency**	High street agency	By employees mainly for desk-based activities and off-street visitors — public area and back office	Weekdays and early evenings, commonly part or all of weekend	2660	Office type of activities, with retail street frontage, and consequent infiltration and glazing losses	Heating, lighting, cooling, employee appliances, standard IT, basic tea room			Bank branches, estate agents, travel agents, legal, insurance and advertising services, off-street professional services, Post Offices, betting shops	140	0	**140**	20%	0%	28.00	11.94	16.95	28.89	**141**
3	**General retail**	General street retail and services	Mainly by clients, customers and visitors for a service activity — some facilities required for employees	Weekdays and early evenings, commonly part or all of weekend	2660	Basic heating, lighting, cooling for off street premises that may contain a wide variety of activities besides sale of goods	Heating, lighting, cooling, appliances for small number of employees			High street store or local stores. Corner shops, amusement arcades, takeaways, hairdressers, laundries, laundrettes, dry cleaners, hire premises, indoor markets	165	0	**165**	15%	0%	24.75	10.56	15.43	25.99	**166**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Name and description			Allocation guides				Further category details				Energy benchmarks for UK			Weather adjustment for UK			Weather adjusted for Malta ($kW{\cdot}h/m^2.yr$)			Bench mark for Malta
4	**Large non-food shop**	Retail warehouse or other large non-food store	Mainly by customers for purchasing goods — some facilities required for employees	Typical week and weekend days	2660	Large, and tends to be solely used for retailing	Heating, lighting, cooling, appliances for small number of employees			Retail warehouses or shed, department stores, hypermarkets, large showrooms	70	170	**240**	0%	55%	93.50	39.88	15.43	55.31	**202**
5	**Small food store**	Small food store	Mainly by customers for purchasing goods — some facilities required for employees	Typical week and weekend days	2660	Greater needs for refrigeration of goods than other shops	Heating, lighting, display cabinets, food storage, employee appliances			Food stores, green grocers, fish shops, butchers, delicatessens	310	0	**310**	15%	0%	46.50	19.83	15.43	35.26	**299**
6	**Large food store**	Supermarket or other large food store	Mainly by customers for purchasing goods — some facilities required for employees	Typical week and weekend days; may be used in evenings; some are 24/7 operations	2860	Greater needs for refrigeration of goods, and larger, than other shops	Heating, lighting, display cabinets, food storage, employee appliances	Covered car park	Bakery oven	Supermarkets and freezer centres	400	105	**505**	0%	55%	57.75	26.77	17.61	44.38	**492**
7	**Restaurant**	Restaurant	Storage and preparation of food which is then cooked and served to users; seating space for eating is provided	There is a wide variety of operational schedules, from selected portion	3060	Assumes minimal reheat of food.	Heating, lighting, cooling, food storage, heating of pre-prepared food		Cooking equipment in a catering kitchen	Cafes, restaurants, canteens, refectories, mess halls	90	370	**460**	20%	30%	129.00	56.91	30.64	87.55	**419**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
	Name and description		**Allocation guides**				**Further category details**				**Energy benchmarks for UK**			**Weather adjustment for UK**			**Weather adjusted for Malta (kW·h/m².yr)**			**Bench mark for Malta**
				s of weekdays to 24/7 operation																
8	**Bar, pub or licensed club**	Bar, pub or club	Serving drinks and snacks, with standing and sitting areas for customers	Open to public or members, day and evening	3060	Major activity is the bar and associated areas	Heating, lighting, cooling, some office appliances, snack provision			Pubs licensed clubs, members clubs, wine bars	130	350	**480**	0%	40%	140.00	61.76	35.75	97.51	**438**
9	**Hotel**	Hotel or boarding house	Primarily the provision of short-term accommodation and hygiene facilities	Primarily used in evenings	6560	Provision for paid short term accommodation	Heating, lighting, cooling, some office appliances, laundry services	Swimming pool, fitness and health centre, restaurant, general office (for conference facility)		All hotel types, guest houses, motels	105	330	**435**	0%	45%	148.50	65.51	33.71	99.23	**386**
10	**Cultural activities**	Museum, art gallery or other public building with normal occupancy	Spaces for displaying and viewing objects, with associated office and storage facilities	Daytime use, similar to office hours but more likely to be open in weekends	2040	Activity is office like in its requirements but with some additional conditioning requirements for display and	Heating, lighting, cooling, humidity control			Municipal museums, libraries and galleries, higher education arts buildings	70	200	**270**	0%	55%	110.00	42.66	16.70	59.36	**219**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
	Name and description		**Allocation guides**				**Further category details**				**Energy benchmarks for UK**			**Weather adjustment for UK**			**Weather adjusted for Malta (kW·h/m².yr)**			**Bench mark for Malta**
						storage of artefacts														
11	**Entertainment halls**	Entertainment halls	Large assembly and seating areas, with associated ticketing and snack services, for performance events and films	Mainly in evenings, some daytime use. All days of week	2548	Tend to be large halls, mainly used in evenings	Heating, lighting, cooling of main entertainment spaces, and circulation. Ticketing and snacks provision			Cinemas, theatres, concert halls. Bingo halls	150	420	**570**	0%	55%	231.00	89.60	23.84	113.44	**452**
12	**Swimming pool centre**	Swimming pool hall, changing and ancillaries	Swimming pool with associated facilities	Ranges from occasional use to daily and evening	2856	Pool hall is the dominant space use — may have small café and fitness room	Heating, lighting, cooling of all spaces. Office appliances, showers, snack provision and bar			Swimming pool centre without further sports facilities	245	1130	**1375**	0%	55%	621.50	322.73	9.19	331.92	**1085**
13	**Fitness and health centre**	Fitness centre	Fitness, aerobics, dance and solarium/sauna facilities	Typical daily and evenings	2754	Provision of sports and entertainment equipment with generally high energy usage, andinternal gains	Heating, lighting, cooling of all spaces. Office appliances, showers, snackprovision and bar			Fitness centre, health centre	160	440	**600**	0%	40%	176.00	86.20	21.46	107.65	**532**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Name and description			**Allocation guides**				**Further category details**				**Energy benchmarks for UK**			**Weather adjustment for UK**			**Weather adjusted for Malta (kW·h/m².yr)**			**Bench mark for Malta**
14	**Dry sports and leisure facility**	Dry sports and leisure facility	Dry sports and club house buildings — for a combined leisure centre include pool etc.	Ranges from occasional use to daily and evening	2754	Provision of space to support separated sporting and entertainment activities often lightly serviced	Heating, lighting and basic office equipment	Swimming pool, fitness and health centre	Sports flood lighting	Dry sports halls, sports grounds with changing rooms, tennis courts with office, speedway tracks, stadiums, pavilions	95	330	**425**	0%	55%	181.50	88.89	21.46	110.35	**354**
15	**Covered car park**	Car park with roof and side walls	Provision for car parking and access	Weekday or 24-hour	4284	Lighting and mechanical ventilation when in use.	Lighting and ventilation	Office, public building in central urban location	Lighting and ventilation	Office, public building in central urban location	20	0	**20**	0%	0%	0.00	0.00	0.00	0.00	**20**
16	**Public buildings with light usage**	Light use public and institutional buildings	Variety of facilities and services provided with generally public access when in use	Intermittent usage	2040	Lightly serviced or lightly used	Heating and lighting				20	105	**125**	0%	55%	57.75	22.40	9.71	32.11	**99**
17	**Schools and seasonal public buildings**	Public buildings nominally used for part of the year	Teaching and community activities	Weekday usage for part of the year	1400	Public buildings with part annual occupancy	Heating, lighting and basic office equipment, teaching equipment, computers	Restaurant (dining hall)		Primary and secondary schools, nurseries, creches, youth centres and community centres	36	105	**141**	0%	55%	57.75	21.23	12.13	33.36	**117**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Name and description			**Allocation guides**				**Further category details**				**Energy benchmarks for UK**			**Weather adjustment for UK**			**Weather adjusted for Malta (kW·h/m².yr)**			**Bench mark for Malta**
18	**University campus**	University campus	Lecture theatres, offices, workshops, eating places, laboratories and other activities	Weekdays and evenings	2660	Large floor space and variety of activities	Heating, lighting, cooling, office and teaching equipment	Laboratory, restaurant	Furnace or forming process	Typical campus mix for further and higher education universities and colleges	80	240	**320**	0%	55%	132.00	56.30	19.06	75.36	**263**
19	**Clinic**	Health centres, clinics and surgeries	Provision of primary health care	Usually week days and early evenings	2040	Daytime use, essentially office hours, but needs to provide for high public use, generally by appointment	Heating, lighting, cooling, hot water services			Doctors surgeries, health clinics, veterinary surgeries, dentist	70	200	**270**	0%	55%	110.00	42.66	31.31	73.97	**234**
20	**Hospital; clinical and research**	Clinical and research hospital	Mainly space for medical care with 24-hour accommodation for patients, with associated operating theatres, laboratories, offices and workshops	Continuous for the majority of the facility	8760	24-hour accommodation with stringent environmental conditions, ventilation control, quarantine, and high occupant servicing needs	All services	Laboratory or operating theatre, restaurant	Furnace or forming process	Acute hospital, specialist hospital, teaching hospital and maternity hospital	90	420	**510**	0%	55%	231.00	156.28	104.99	261.27	**540**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Name and description			Allocation guides				Further category details				Energy benchmarks for UK			Weather adjustment for UK			Weather adjusted for Malta (kW·h/m².yr)			Bench mark for Malta
21	**Long term residential**	Long term residential accommodation	Full accommodation, including sleeping space, day time space, all domestic facilities, some office facilities	Continuous	8760	24-hour fully conditioned and serviced accommodation	Heating, lighting, cooling, appliances, food and hot water services, entertainment, laundry	Restaurant (dining hall)		Residential home, homeless unit, cottage hospital and long stay hospital, detention centres and prisons	65	420	**485**	0%	55%	231.00	156.28	104.99	261.27	**515**
22	**General accommodation**	General accommodation	Space for sleeping, showers, basic domestic services	Non-continuous occupancy, often only used in evenings	2940	Slow turnover of occupants requires fewer facilities and less laundry than for example a hotel	Heating, lighting, cooling, laundry and drying rooms			Boarding houses, university and school hostels, homeless units, nursing homes	60	300	**360**	0%	55%	165.00	68.72	13.82	82.54	**278**
23	**Emergency services**	Emergency services	Offices, accommodation, food services, cells, garaging and other activities as required	Normally continuous, some stations closed in the evenings and weekends	8760	Provision of a variety of services that would be in separate categories in other parts of the non-domestic stock (e.g. accommodation, offices and vehicle garaging)	Heating, lighting, cooling, food services, office and training equipment			Police, fire and ambulance stations	70	390	**460**	0%	55%	214.50	145.12	104.99	250.10	**496**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Name and description			Allocation guides				Further category details				Energy benchmarks for UK			Weather adjustment for UK			Weather adjusted for Malta (kW·h/m².yr)			Benchmark for Malta
24	**Laboratory or operating theatre**	Laboratory or operating theatre	Special equipment and conditions in at least 30% of floor area	Either weekday or 24-hour multi-shift	2040	Spaces requiring controlled ventilation and conditions	Heating lighting, ventilation		Furnace or forming process	Research chemical laboratory, hospital operating theatre	160	160	**320**	0%	55%	88.00	34.13	31.31	65.44	**297**
25	**Public waiting or circulation**	Bus or train station, shopping centre mall	Public circulation or waiting facilities	Variable — intermittent to continuous	2040	Waiting and circulation areas, booking desks, boarding facilities	Heating, lighting, cooling, snack services	Retail		Bus stations, local train stations, shopping centre malls	30	120	**150**	0%	55%	66.00	25.60	24.12	49.72	**134**
26	**Terminal**	Regional transport terminal with concourse	Waiting and boarding facilities for air, ship or regional/international train travel	Daytime and evenings each day to near continuous	8760	Concourse areas, booking areas, identification, customs, security and baggage handling	Heating, lighting, cooling, baggage handlings	Retail, restaurant, covered car park		Large train stations, airport terminals	75	200	**275**	0%	55%	110.00	74.42	37.33	111.75	**277**
27	**Workshop**	Workshop or open working area (not office)	Facilities for light mechanical work	Generally working week but can be multi-shift	2040	Goods access, mechanical tools and facilities	Industrial heating and lighting standards		Furnace or forming process	Workshops, vehicle repair	35	180	**215**	0%	55%	99.00	38.40	11.13	49.53	**166**
28	**Storage facility**	Storage warehouse or depot	Storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2040	Lightly serviced long term storage areas	Low level lighting and heating in storage areas			Distribution warehouse without public areas, and local authority depot	35	160	**195**	0%	70%	112.00	43.44	7.42	50.86	**134**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Name and description			**Allocation guides**				**Further category details**				**Energy benchmarks for UK**			**Weather adjustment for UK**			**Weather adjusted for Malta (kW·h/m².yr)**			**Bench mark for Malta**
29	**Cold storage**	Refrigerated warehouse	Refrigerated storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2660	Refrigerated long term storage areas	Refrigeration, lighting and heating of handling areas		Blast chilling or freezing plant	Refrigerated warehouse without public areas	145	80	**225**	0%	55%	44.00	18.77	8.47	27.24	**208**

The results of Table 5-19 are reproduced graphically in Figure 5-17. This chart shows the weather-independent (red) and the weather-dependent (orange and blue) energy use intensities for each categorised benchmarked non-residential building in Malta.

When comparing the harmonised EUIs to those of the UK,(as shown in Figure 5-16), Malta's EUI s related to the yield of the outside ambient temperature (orange part) are not as harsh as those of the UK. They are around 40% those of the UK.

On the other hand, Malta's benchmark EUIs have the added latent load due to the ventilation air (blue) when the cooling equipment is running during the hot and humid summers. Practically this load depends on the type of building, occupation density, operation schedules and the request for enhanced indoor air quality.

As one can see from the chart, the highest energy use is in the range of 1200kWh/m^{2}yr and goes towards indoor swimming pools (Cat 12). Nearly twice as much as the others in both weather-dependent and weather-independent conditions. The highly weather-independent conditions are attributed to maintaining pool water temperatures around 26^{o}C; and the weather-dependent conditions are required to keep the pool at around 1 or 2 degrees Celsius above that, to lessen body shock when exiting the water and to suppress water vaporisation from the pool's surface; which would be both damaging and highly increase energy and financial consumption. Thus, dehumidifiers must be employed in these premises. Dehumidifiers, in turn, consume a high amount of energy. Since Malta is completely surrounded by sea, such complexes are not so common.

Next in line come hospitals (cat 20) and similar healthcare buildings with an energy consumption in the region of 550kWh/m^2 yr having almost equal weather-dependent and independent energy use intensities. The weather independent are attributed to the extensive amount of machinery and technologies to cure patients. On the other hand, the high weather dependent EUIs are equally divided between the requirements to keep the inside of the building in good climate control and good indoor air quality (IAQ) for sanitary purposes, as well as to ensure the sensible load of unpredicted occupants.

Next in line for energy use in the rage of 400kWhm^{2}yr are the hospitality services such as hotels (cat9), bars and large shopping malls, etc. for which the occupational density is very variable and difficult to control. Offices or similar buildings such as those covered by categories 1 to 6, consume relatively less energy, usually in the range of 200kWh/m^{2}yr. This is so because they have a very well controlled type of ventilation with an identified occupation and an operating schedule.

On the other hand, these EUIs diminish to zero for category 15, i.e. a covered car park which is heavily ventilated, but the air is not treated so that there is no change in the moisture content, while inside temperature is left floating.

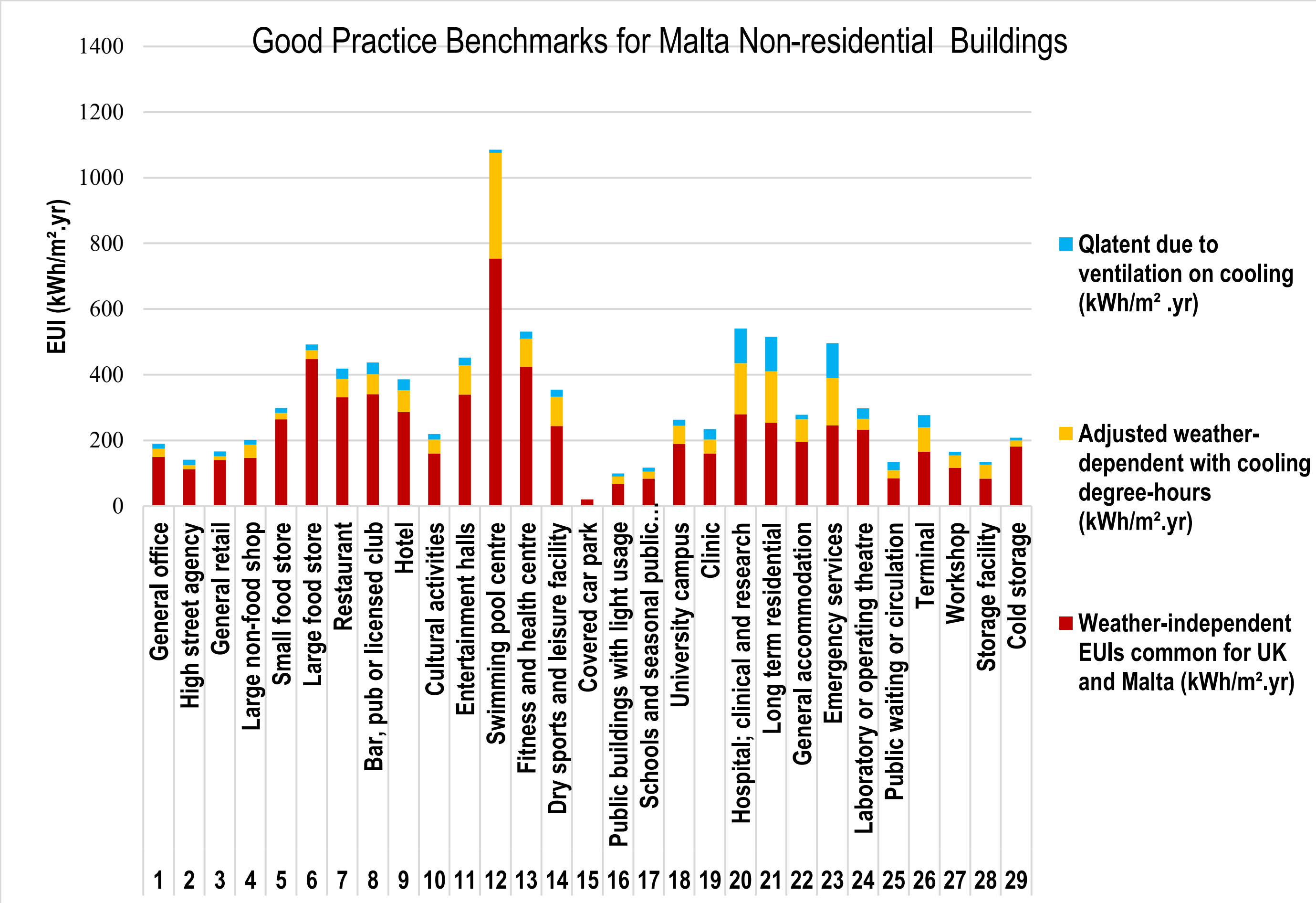


Figure 5-17: Malta weather-independent and weather-dependent (DD and latent load) adjusted EUIs for non-residential buildings benchmarks

5.7 Summary

Currently the average EUIs of the EPCs are being used as benchmarks for new or renovated non-residential buildings in Malta and other Member States. From the previous chapters it was concluded that the calculation methodology lacks definitive clarity, the results are not reliable when compared to actual readings and make it difficult to predict current scenarios.

This chapter has proposed a different approach with regards to benchmarking that can be used as Key Performance Indicators (KPIs) for energy use intensity, to be able to categorise non-residential buildings and to create a yardstick that can be used by building designers, energy managers and policy makers especially when comparing these benchmarks to the actual on-site energy use.

These energy benchmarks have been formed based on the fact that good-practice non-residential buildings around the world would have typical use that is very similar at base load which is influenced by the type, class, design, operation and maintenance of the building, similar to all locations globally, with an added component that is climate and weather dependent. Additionally, for cooling demand load countries, the added energy needs for cooling due to the latent heat in ventilation has to be considered.

The popular UK 29 categorised benchmarks for good practice are built on rigorous studies [69] for optimising energy efficiency in buildings, were harmonised through the degree day method and adapted from a predominantly heating country such as the UK, for a Malta's predominantly cooling needs, using local meteorological databases.

Furthermore, for each category benchmarked building, the additional latent load due to ventilation was calculated and added, for which the airflow rates were calculated on the PMV-PPD using the minimum air required for breathing as well as to remove pollutants from personnel and the low-polluting building fabric to EN16798 standards. For each category, the difference in moisture content between outside and inside air was calculated using 3 consecutive years of local hourly weather data and basing the calculations on established empirical formulae to calculate the hourly outside moisture content from the hourly dewpoint external temperature.

From the above results it can be easily seen that although Malta has less than 70% of the total annual degree days its EUIs are nearly similar for each categorised building. This is due to the high latent load generated from its hot and humid summers.

Such benchmarks are particularly useful for their simple features. They are flexible enough to be used by different performers. They are multipurpose and applicable to different types of buildings. They are easy to use and visualise. These benchmarks will be extremely useful in bottom-up and top-down auditing especially for filtering data, in clustering of non-residential buildings for specific analyses. Therefore, as in the game of bocce, such benchmarks are the jack and the winner, is one who get nearest to the mark. It is agreeable that improvements on these benchmarks can be done especially knowing the influence of the solar gain factor on buildings' outside surfaces, a feature of Malta's landscape and wider geographic environment; and the application of the Variable-Base Degree-Day Method [105] to offset this phenomena. The key factor will be the widespread use and application of these systems and certificates to form a large database so that such benchmark EUIs may be trimmed accordingly.

In the next chapter, the results will be compared to the three clusters that were studied in terms of their actual energy performance to validate the proposed approach of this thesis.

6 COMPARISON OF RESULTS BETWEEN THE PROPOSED SOLUTION AND THE ACTUAL ENERGY CONSUMPTION OF THE THREE BUILDING CLUSTERS

6.1 Introduction

This chapter draws a comparison between the actual energy consumption of the three cluster buildings case studies and their corresponding good practice benchmarks as calculated in this thesis.

The solution as explained in Chapter five proposes a different approach from that of asset rating EPCs, to that of operational EPCs, based on actual energy readings. This is the intended new direction as suggested in the updated EPBD (EU) 2018/844. However, the EPBD falls short of recommending any methodology to determine the benchmark EUIs.

In this thesis, the proposed approach was to divide the EUI into weather-independent and weather-dependent components. Using appropriate studies and scholarly literature, it was demonstrated that the weather-independent component for the different categories of non-residential buildings is practically the same everywhere, such as the energy consumption for lighting or domestic water heating, as well as for services such as pumps, lifts and catering. On the other hand, the weather-dependent component mainly concerns space heating, space cooling and ventilation all related to thermal comfort. In particular, it was shown that energy demand for cooling needs to take into consideration both the sensible, as well as the latent heat of the air and this is strongly dependent on the weather of the site. The addition of these two components, weather-independent and weather dependent would eventually give the overall EUI benchmark for that category of non-residential building.

In the case of existing buildings, the methodology to arrive at these EUIs is as follows :

a) access annual energy use bills;
b) estimate total electricity and fuel energy use;
c) establish the useful floor area;
d) estimate occupancy factors;

e) establish weekly time schedule and operating hours;
f) divide the energy used by the floor area to get the EUIs;
g) select the category type benchmark for the applicable building;
h) if necessary, harmonise the actual operating schedules to the benchmark operational schedules for that category of building, as given in Table 5-19. This will ensure that the actual building EUI has the same baseline as the corresponding EUI of the category benchmark;
i) compare and rate the EUI of the building to the appropriate benchmark EUI in column U of Table 5-19;
j) present the results on how the building's EUI compares to the benchmark.

On the other hand in the case of new designs and renovated buildings [138], the procedure is as follows:

a) calculate floor areas;
b) estimate operating hours and occupancy factors;
c) calculate energy use for space heating, cooling, fans and pumps based on appropriate engineering practices;
d) calculate energy use for humidification and dehumidification, based on sound engineering principles;
e) calculate lighting energy use, based on appropriate lighting design;
f) calculate energy use for lifts and escalators, based on actual equipment use;
g) estimate energy use for small power;
h) evaluate energy use for catering;
i) estimate energy use for server rooms;
j) evaluate energy use for other equipment;
k) calculate energy consumption for domestic hot water;
l) add the total energy consumption and consider any necessary adjustments that may need to be made due to variation, between the calculated energy consumption and the actual operation of the building or any forecasted changes in operation;
m) review against the good practice benchmarks as shown in Table 5-19;

n) present the results on how the building's EUI compares to the benchmark.

The calculated benchmarks of Chapter 5 for non-residential buildings are considered to be good practice benchmarks, which means that they waste less energy, and are thus more efficient. If nothing has been done to save energy in a particular building and resulting in an EUI that is higher than the established benchmark for its category, then the chances are that assessors will find many opportunities for improving the energy performance of that building to bring it closer to the best practice benchmark. As explained in the previous chapter, to get a realistic EUI, especially for complex buildings, an in-depth study of the building and services is required through a bottom-up approach.

6.2 Comparison of calculated Malta benchmarks with those of UK

As shown in Figure 6-1, although Malta's total DD is 30% lower than that of the UK, the difference between the EUIs for the 29 different categories is not so large. Notwithstanding the fact that the Maltese benchmarks took the actual number of hours for cooling equipment operation, during occupancy hours only. This is very conservative in the sense that Malta, as shown in Figure 4-11, has a very low diurnal variation in summer of just 7°C. Diurnal temperature variation is the difference between the highest and lowest temperatures that occur during the same day. For peak design temperature of, e.g. 36°C, the minimum temperature of 29°C is necessary at night, so the building can be passively cooled. The additional energy stored in the building's structure would then have to be removed by the cooling plant during the operational hours.

The schedule of energy use intensities as given in Table 5-19 must be read in its entire configuration for all columns of the appropriate row. If the building under study has glaring differences from the corresponding benchmark inputs, in terms of services, occupancies or operational schedules, then these must be harmonised to those of the benchmark, before being able to compare the building's EUI to its corresponding benchmark.

Furthermore, where facilities as detailed in column I of Table 5-19 do not exist, one has to create a composite typical installation EUI for the overall performance of the building, engineered in such a way so as to compare like with like with the benchmark, by combining the area-weighted installation. For example, when a building under investigation lacks an important facility that forms a key component of the benchmark in Table 5-19, (for example a school that has no restaurant when the benchmark includes a restaurant), then it is important to first estimate the size (i.e. the required floor area A_{rest}) of the restaurant by factoring in the number of students in the school. This can be easily obtained from standard architectural principles and standards [156]. Then, the EUI benchmark for good practice restaurants EUI_{rest} is taken for the appropriate category found in the 29 categories and multiplied by the estimated restaurant's area. The resulting correctly weighted EUI for the school $EUI_{weighted}$ can be calculated based on the weighted areas, as shown in Equation 6-1 below:

$$EUI_{weighted} = \frac{EUI_{School}\ x\ Area\ of\ school + EUI_{Restaurant}\ x\ Area\ of\ restaurant}{Area\ of\ School + Area\ of\ Restaurant} \qquad (6\text{-}1)$$

Figure 6-1 shows the difference between the proposed harmonised Malta and UK benchmarks EUIs. When looking at the overall difference between the UKs and Malta's EUIs, it is clear that for those buildings that require high ventilation rates such as categories 20, 21 and 23, the EUI for Malta supersedes those of the UK.

As shown in Table 6-1 when looking at the overall difference between the UK's and Malta's EUIs for the 29 non-residential categorised good practice benchmark buildings, the overall difference varies approximately between +8% and -39%, being negative for those buildings that do not have high ventilation requirements, such as, schools and stores.

On the other hand, the remaining non-residential benchmark buildings categorised for good practice, have very similar EUIs as those of the UK, in spite of the fact that the degree days for Malta are much lower than those of the UK. The main load is the high latent heat due to high moisture content in the air needing to be removed.

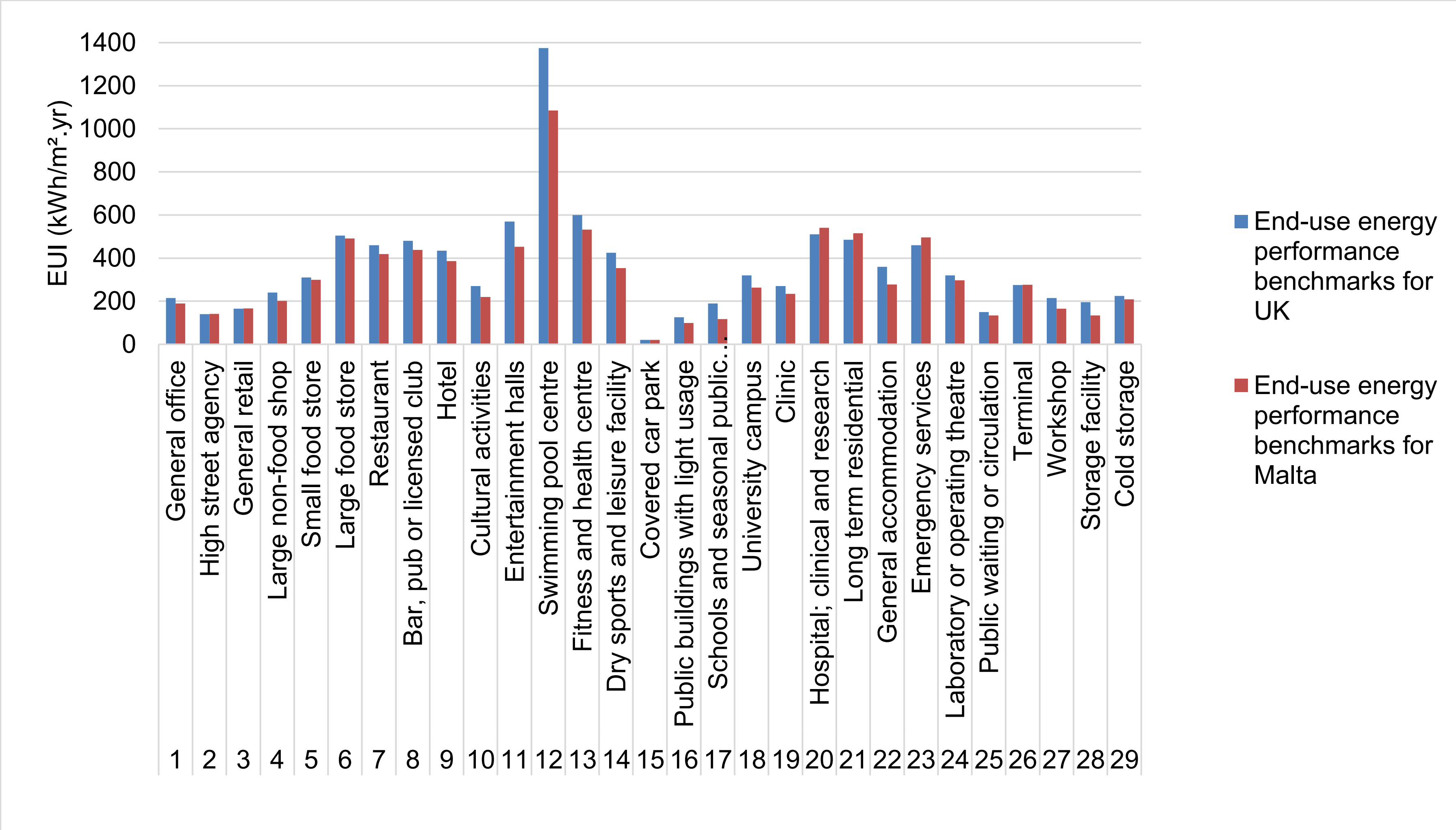


Figure 6-1: Comparison of good practice EUIs (kWh/m^2.yr) benchmarks for UK and Malta

In Table 6-1 the benchmark EUIs are arranged in ascending order of percentage difference. When looking at this table, it is clear that the categories may be grouped into three, those having EUIs similar to Malta within ±10% (brown), EUIs within -10 to -20% (yellow) and EUIs with over 20% difference (blue).

It is clear that the percentage difference between the three groups is not normally distributed, even though the same methodology was used to determine the 29 EUIs for Malta. In comparison, the EUIs for the two offices i.e. category 2, (brown band) has 1% divergence; and category 1, (yellow band) has -12% difference. Thus, it becomes imperative to further investigate these variations. The category 1 office had a yearly EUI of 95kWh/m^2 of electrical energy use, with 0% related to weather dependence and 120kWh/m^2 of thermal fuel with 55% weather-independent for the UK case as shown in Table 6-2. It is clear that in this category, the office electricity is fully dedicated to weather-independent energy consumption, while the fossil thermal load is used for space heating with more than half of it being weather-dependent. Therefore, in this case, when the calculations were carried out for Malta, the 55% weather-dependent component had a lower impact on Malta's EUI, given that the total degree-days are lower for Malta. This created the discrepancy of 12%.

On the other hand, the category 2 office – which had a heavier electricity use nearly double that of category 1 – indicates that electricity is being used for HVAC as well as equipment (as is the case of Maltese offices), with 20% allowed for weather-dependent electrical energy use. As a result, the EUI for Malta was found to be similar to that of the UK for category 2, even though Malta has fewer total degree-days.

Table 6-1: Comparison of the proposed good practice EUIs for Malta with the UK's benchmarks for non-residential buildings

Cat	Building Type	Country Brief description	UK Total (kWh/m^2.yr)	Malta Total (kWh/m^2.yr)	% difference
17	**Schools and seasonal public buildings**	Public buildings nominally used for part of the year	190	117	-39%
28	**Storage facility**	Storage warehouse or depot	195	134	-31%
27	**Workshop**	Workshop or open working area (not office)	215	166	-23%
22	**General accommodation**	General accommodation	360	278	-23%
12	**Swimming pool centre**	Swimming pool hall, changing and ancillaries	1375	1085	-21%
11	**Entertainment halls**	Entertainment halls	570	452	-21%
16	**Public buildings with light usage**	Light use public and institutional buildings	125	99	-21%
10	**Cultural activities**	Museum, art gallery or other public building with normal occupancy	270	219	-19%
18	**University campus**	University campus	320	263	-18%
14	**Dry sports and leisure facility**	Dry sports and leisure facility	425	354	-17%
4	**Large non-food shop**	Retail warehouse or other large non-food store	240	202	-16%
19	**Clinic**	Health centres, clinics and surgeries	270	234	-13%
1	**General office**	General office and commercial working areas	215	189	-12%
13	**Fitness and health centre**	Fitness centre	600	532	-11%
9	**Hotel**	Hotel or boarding house	435	386	-11%
25	**Public waiting or circulation**	Bus or train station, shopping centre mall	150	134	-11%
7	**Restaurant**	Restaurant	460	419	-9%
8	**Bar, pub or licensed club**	Bar, pub or club	480	438	-9%
29	**Cold storage**	Refrigerated warehouse	225	208	-7%
24	**Laboratory or operating theatre**	Laboratory or operating theatre	320	297	-7%
5	**Small food store**	Small food store	310	299	-4%
6	**Large food store**	Supermarket or other large food store	505	492	-3%
15	**Covered car park**	Car park with roof and side walls	20	20	0%
2	**High street agency**	High street agency	140	141	1%
26	**Terminal**	Regional transport terminal with concourse	275	277	1%
3	**General retail**	General street retail and services	165	166	1%
20	**Hospital; clinical and research**	Clinical and research hospital	510	540	6%
21	**Long term residential**	Long term residential accommodation	485	515	6%
23	**Emergency services**	Emergency services	460	496	8%

Table 6-2:Weather-dependent and weather-independent EUIs for UK and Malta

A	B	L	M	N	O	P	Q	R	S	T	U
Name and description		**Energy benchmarks for UK (kWh/m².yr)**			**Weather adjustment**			**Weather adjusted for Malta (kWh/m².yr)**			**Bench mark for Malta**
Cat	**Name**	**Electricity typical benchmark**	**Fossil-thermal typical benchmark**	**Total (kWh/m².yr)**	**Percent of electricity benchmark pro-rated to degree-days**	**Percent of fossil-thermal benchmark pro-rated to degree-days**	**Total for weather adjustment of 2021 DD**	**Adjusted Malta TDD when cooling plant is on**	**Q_{latent} due to ventilation on cooling (kWh/m².yr)**	**Total energy due to weather (kWh/m².yr)**	**Total Energy usage per unit area (kWh/m².yr)**
1	**General office**	95	120	**215**	0%	55%	66.00	25.60	14.84	40.44	**189**
2	**High street agency**	140	0	**140**	20%	0%	28.00	11.94	16.95	28.89	**141**

Clearly, for the case of Malta only few categories use fossil thermal energy for heating, such as in hotels and hospitals. Therefore, the impact of the heating degree-day on that component would be significant, given that Malta's heating DDs are much lower than those of the UK. On the other hand, these same buildings in Malta depend heavily on electrical cooling systems, which implies that the latent heat during cooling would add up more energy to that category, which offsets the lower heating demand. As a result, the percentage difference between that of the UK and Malta for such particular buildings is small.

Given that all the categories are non-residential buildings with relatively similar operational hours all over the world, there is nothing to suggest that the weather-independent EUIs should be different. From scholarly literature [138] it has been shown that the OR methodology has been used for quite a number of years and there is nothing to suggest that the weather-independent components of the EUIs are not appropriate.

The EUI for schools is at -39% difference and has the highest change, because:

- Firstly, schools in the UK benchmark include an indoor pool. This is rare in Malta's schools, so the UK EUI was adjusted to remove the pool. If pools are to be included in a particular school in Malta, then this benchmark needs to be adjusted separately, because pools have high EUIs.
- Secondly, energy use intensity (EUI) is different to energy use. In energy modelling, an EUI offers another dimension for observations and calculations to be made. Schools' EUIs are highly weather-dependent, while the weather-independent (mainly equipment) components are relatively small per unit area. The change to the weather-dependent variable due to lower DD is mostly based on cooling degree-hours (a smaller value) resulting in a large change in the EUI. It is the sensitivity of the EUI to degree days, which gives this discrepancy.

When looking at other categories that have very small difference such as car parks, the impact of the weather on cooling and heating is nil, because the building is unconditioned. The need for ventilation remains but its energy consumption is accounted for as equipment only.

6.3 Comparison of EUIs of Cluster building case studies to benchmarks

This section compares the resulting good practice benchmarks of the three clusters studied in Chapter 4 to their actual EUIs.

6.3.1 Cluster type 1 educational buildings, schools and collages

As per allocation list given in Figure 2-23, these types of educational buildings, fall under benchmark category 17, i.e. *Schools and seasonal public buildings* with a teaching and community variety of facilities and services provided with generally public access when in use for 1,400 hours per year, as given in column G of Table 5-19. The good practice energy use for this benchmark building is 117kWh/m^2 yr. They include energy required for heating, lighting, basic office equipment, teaching equipment, computers, and a restaurant as distinctive features. In the original UK TM46 benchmark such a category included the building's capacity for an indoor pool in a separate addendum [157]. The consumption for a pool at a school was given as 30% for fuel and 10% for electricity consumption. Subsequently this table was corrected because such pool facilities are rare for schools in Malta.

The four schools under consideration, as well as many other primary and secondary schools in Malta are not air-conditioned and do not have restaurants. Consequently, this study went on to calculate the HVAC consumption, domestic hot water and lighting loads, and when these were added up to the school related equipment load for the four schools and area-weighted averaged already surveyed, resulted in an energy use intensity of 110.53kWh/m^2.yr as shown in Table 6-3.

Table 6-3: Summary of the calculated EUIs for schools with HVAC

College	St Ignatius College Middle and Secondary Schools	Maria Regina College Mosta Secondary School	St Clare's College Pembroke Secondary School	
Location	Ħandaq	Mosta	Pembroke	
Area (m^2)	25,336	7,637	11,727	
System	Annual Energy Use Intensity			Area weighted averaged
	kWh/m^2 .yr.			kWh/m^2 .yr.
Heating	8.31	12.40	7.18	8.71
Cooling	30.17	36.36	43.14	34.63
Auxiliary	8.79	7.11	5.56	7.66
Lighting	21.17	25.43	27.42	23.54
Hot water	27.04	42.41	27.85	29.88
Total	**90.98**	**123.71**	**111.15**	**104.41**
School equipment as measured on site	**4.81**	**9.04**	**7.05**	**6.12**
Total every energy use intensity (EUI) to compare with benchmark				**110.53**

However, one has to keep in mind that this benchmark as worked out from the UK scenario, included a restaurant with high energy use intensity more than that of a typical school as explained in column I of Table 5-19.

To allow for such a restaurant, one has to use the multivariate approach [153], which uses a large number of variables to the energy use intensities of a specific building enabling the comparison of a typical building with the same features. Such variables may include building layout, operation schedules, activities or climate location. This approach is used extensively in the DECs [120] or the US Energy Star [112] building performance certification.

Between them, these four schools have around 2,188 students and 525 staff [158], [159]. From the UK's research document [160] on catering specification for educational facilities, a kitchen which could provide a full service or support would have to include a full complement of spaces to allow for food storage and preparation, thus requiring an area of 1440m^2. If to this, one adds the restaurant with a capacity of approximately one third of the students and staff, simultaneously, and an occupation density of 5m^2 per person as given in table 5-14, then an additional area of 5,057m^2 for all schools would be required. These values can be used to modify the original typical installation EUI by multiplying this restaurant/kitchen area with its relative harmonised EUI of 419kWh/m^2 (category 7 restaurant from Table 6-2). Next, it would be necessary to area-weight it with the originally measured/calculated school EUI (similar to that shown in Equation 6-1), to give a revised energy use intensity of 141.4kWh/m^2.yr, as shown in Table 6-4. This is around 20.1% higher than the good practice benchmark and is considered acceptable, given that the schools are currently running as typical with only a few energy efficient measures in place.

Table 6-4: Area-weighted EUI for school with restaurant

Students	2188	no.
Staff	525	no.
Total	2713	no.
Kitchen area	1440.0	m^2
Restaurant area	3617.3	m^2
Restaurant area + kitchen for 4 schools	5057.3	m^2
Adjusted benchmark EUI with restaurant	419.0	$kWh/m^2.yr$
As calculated and measured		
EUI as measured on site	110.0	$kWh/m^2.yr$
Area	44,700.0	m^2
EUI adjustment area-weighted average for typical installation	**141.4**	$kWh/m^2.yr$
Cat 17 schools benchmark harmonised for Malta without pool	**117.0**	$kWh/m^2.yr$
Percentage difference	**20.10%**	

6.3.2 Cluster type 2 modern block of offices

The 2017 measured actual electrical energy used for this office block housing the headquarters of an international financial institution was taken from the 12 actual billing meters on both floors amounting to 166kWh/m^2.yr as given in Table 6-5 below. This energy intensity was very consistent along the preceding six years period (see Table 4-17), working from 8am till 5pm on weekdays and from 8am to 1pm on Saturdays.

Table 6-5: Office block EUI throughout 2017

Electricity bill date	31st December 16	30th December 17	Difference
	kWh	kWh	kWh
Ground Floor			
Office sub-distribution board	1,302,609.0	1,510,021.0	207,412.0
Office A/C	527,519.0	616,011.0	88,492.0
Total Ground Floor			**295,904.0**
Lifts			
Office lift 1	11,867.0	13,739.0	1,872.0
Office lift 2	12,105.0	14,198.0	2,093.0
Total for lifts			3,965.0
First Floor			
Office sub-distribution board	543,399.0	630,742.0	87,343.0
Office a/c	490,670.0	562,405.0	71,735.0
Total for First Floor			**159,078.0**
Common Areas:			
Distribution board, 2A	78,503.0	91,051.0	12,548.0
Distribution board, 2B	97,154.0	113,418.0	16,264.0
Distribution board, 1B	104,307.0	117,774.0	13,467.0
Distribution board, 1C	86,023.0	100,536.0	14,513.0
Ventilation 1	104,687.0	122,288.0	17,601.0
Ventilation 2	64,385.0	86,689.0	22,304.0
Fire pump set	16.0	30.0	14.0
Total Common Area			**96,697.0**
Common area GF = 26.79%			25,905.1
Common area FF = 43.75%			42,304.9
Shared percentage of Common Area			**68,210.1**
GF LIFTS = 140 out of 282 employees.			1,968.4
FF LIFTS = 130 out of 282 employees.			1,827.8
Ground floor consumption			323,777.6
First floor consumption			203,210.8
Total energy consumed for 2017 kWh			**526,988.3**
Floor area		m^2	3,174.5
Energy Use Intensity for 2017		**kWh/m^2 per year**	**166.0**

In the harmonised benchmarks, presented in Table 5-19, there are two categories for an office building as shown in Table 6-6, namely:

a) Category 1 which works only on weekdays and has a restaurant and a covered carpark with an EUI of 189kWh/m^2.yr.
b) Category 2 which works on weekdays and an extra 5 hours on Saturday and has no other facilities as detailed in Table 5-19, because it is more of a high street agency, with an EUI of 141kWh/m^2.yr.

Table 6-6: Category allocation for office block

No.	Building type	Benchmark category	Category name
1	Adult education centre	1	General office
2	Air traffic control	1	General office
3	Bank office	1	General office
4	Building society office	1	General office
5	Business units	1	General office
6	Call centre	1	General office
7	Central government office	1	General office
8	Commercial office	1	General office
9	Conference centre	1	General office
10	Courts	1	General office
11	Crown and county courts	1	General office
12	Crown court	1	General office
25	Professional/design	1	General office
26	Professional services, off-street	1	General office
27	Public sector offices	1	General office
28	Simulator	1	General office
29	Studio office	1	General office
30	Town hall	1	General office
31	Warehouse office	1	General office
32	Bank or building society	2	High street agency
33	Betting shop	2	High street agency
34	Estate agents	2	High street agency
35	Insurance brokers	2	High street agency
36	Legal/insurance/accountants	2	High street agency

When selecting Category 1, which is most appropriate for this type of office block building, it is necessary to adjust the actual EUI to reflect the requirements of the benchmark to measure an area-weighted average composite EUI.

The operating hours need not be adjusted because as specified in TM46 this will only apply if they exceed 8,760 hours, as shown in Figure 6-2. Therefore, there is also no need to adjust either the electricity or the fossil fuel consumption.

[A]	[B]	[C]	[V]	[W]	[X]	[Y]	[Z]
Name and description			Occupancy adjustment for days and hours of use				
Category	Name	Brief description	Definition of annual occupancy hours in this sector	Reference hours per year	Maximum allowed hours per year	Percentage increase in electricity benchmark at maximum allowed hours per year	Percentage increase in fossil-thermal benchmark at maximum allowed hours per year
1	General office	General office and commercial working areas	Number of hours when the recorded number of occupants exceeds 25% of the nominal maximum number.	2040	8760	107%	44%
2	High street agency	High street agency	Number of hours when the premises are fully open to customers according to published hours.	2448	3672	22%	0%

Figure 6-2: Part of TM46 showing operational schedule adjustments

On the other hand, the EUI of this office needs to be adjusted to include a covered carpark and restaurant, using the same method as that used for Cluster type 1. One has to note that this office block already has 2 medium-sized surface carparks, which is not part of the benchmark and cannot be included as it has no energy consumption. However, the office also shares a common underground garage with third parties, and this would need to be partly considered in the EUI calculation (20 car slots in total) of 20kWh/m^2.yr to cover 200 m^2 of area.

Finally, the restaurant and kitchen are not considered in the original EUI of the office. In order to consider the added zone of a restaurant with kitchen, deference must be made to the guidelines and specifications, e.g. US Department of Defence Education Activity [160], on typical area required per person and typical number of people present in the restaurant at any one time. Based on this deference, and shown in Table 6-7, an additional 606m^2 for food preparation, storage and servicing would need to be added to the building to harmonise it to Category 2 benchmark's key features. When the resulting car park EUI and the restaurant EUI were combined with the measured EUI, based on the same approach as that of Equation 6-1, the final adjusted EUI for the office was found to be 197.2kWh/m^2.yr, as shown in Table 6.7 below.

Table 6-7: Area-weight EUI for typical installation adjustment of office block

Car Park		
Carpark floor area	200.0	m^2
Car bay	10.0	m^2
No. of cars	20.0	
Benchmark	20.0	$kWh/m^2.yr$
Restaurant		
No. of employees	282	No
Shift-splitting	3.0	No
Restaurant meals	94.0	meals
Kitchen size full service	230.0	m^2
Occupation density	4.0	m^2/ person
Restaurant size	376.0	m^2
Restaurant area + kitchen	606.0	m^2
Benchmark for restaurant	419.0	$kWh/m^2.yr$
As measured		
EUI as measured on site	166.0	$kWh/m^2.yr$
Total area	3174.0	m^2
Area-weighted adjustment for typical installation of office with car park and restaurant	**197.2**	**kWh/m^2**
Cat 1 office harmonised for Malta with restaurant and car park	**189.0**	**kWh/m^2**
Percentage difference	**4.3%**	

This small difference of 4.3% between the good practice benchmark of 189kWh/m².yr, and the existing EUI of the office of 197.2kWh/m².yr, indicates that the office has a good performance.

In comparing this office to category 2, i.e. similar to a small high street office, the relation is straightforward and there is no need for adjustment, because the operating schedules as well as the descriptive facilities available for the case study and the benchmark are practically the same, as per Table 5-19. This office building with an actual EUI of 166kWh/m^2.yr is higher than the Category 2 good practice benchmark of 147kWh/m².yr by 17%, which suggests that this category is not the correct category to use for this office, because it is of a lower class of offices, i.e. offices that operate in a cellular mode rather than a central mode. In other words, Category 2 offices are for offices that fall under Cluster 1 type buildings.

6.3.3 Cluster type 3 hospital buildings – Mater Dei Hospital

It is a fact that hospitals are complex buildings with unique energy requirements. They are occupied twenty-four hours a day all year round by a large number of people. Patients are normally unwell and sensitive to environmental conditions for which medical briefs call for a tough steady control of the thermal environment and of indoor air parameters, especially in emergency departments, out-patients, and operating theatres, ITUs and cardiac intensive care units. The electricity and fuel consumption of hospitals exceeds that of many other non-residential buildings. This is mainly due to the use of specialist medical equipment, such as in imaging, IT equipment, CSSDs, laundries, food preparation and storage facilities [88].

In the harmonised benchmarks, this building falls under Category 20, i.e. hospital; clinical and research space for medical care with 24-hour accommodation for patients, and associated operating theatres, laboratories, offices and workshops, etc. having a good practice EUI benchmark of 540kWh/m^2.yr for all services and equipment, as detailed in Table 5-19.

As highlighted in Chapter 4 for this type of building, the Mater Dei acute general teaching hospital had its actual electricity and fuel consumption bills taken at the first input source i.e. at Enemalta's incoming 33KV substation and fuel depot at the entrance. This was examined over 3 consecutive years and the EUIs were found to be between 213 and 269kWh/m².yr. When one compares these EUIs to the good practice EUI of 540kWh/m^2.yr for the calculated benchmark for Hospitals category 20, it is clear that Mater Dei is operating at a much better EUI than the good practice benchmark, as shown in Table 5-19.

Table 6-8: Mater Dei Hospital total Energy Usage Index for 2014 to 2016

Annual use	**Units**	**2014**	**2015**	**2016**
Floor area	m^2	249,587	249,587	274,611
Electricity Consumed	kWh	41,155,200	47,389,533	55,445,900
Unit Electrical load	**kWh/m^2**	**165**	**190**	**202**
Qty of fuel used	Litres	1,177,800	1,536,900	1,799,584
Density @ 15°C	kg/m^3	860	860	860
Weight of fuel	kg	1,012,908	1,321,734	1,547,642
Gross calorific value (10300 kcal/kg)	MJ/kg	43.1	43.1	43.1
Total fuel energy consumed per year	MJ	43,656,335	56,966,735	66,703,381
	kWh	**12,127,730**	**15,825,359**	**18,530,199**
Unit fuel energy consumption	**kWh/m^2**	**49**	**63**	**67**
Total unit energy consumption	**kWh/m^2**	**213**	**253**	**269**

However, when one examines this deeper, Mater Dei Hospital has a large covered carpark, which is not mentioned in the facilities provided by the harmonised benchmark. This falls under category 15 with an annual energy use intensity of 20kWh/m^2.yr. Therefore, the energy consumed and the useful area, need to be adjusted accordingly to reflect only the energy used for the hospital.

As illustrated in Table 4-24, this underground carpark has an area of 70,740m^2, which when factored with an EUI of 20kWh/m^2.yr and subtracted from the metered total, gives an area-weighted averaged EUI of 345.55kWh/m^2.yr, as shown in Table 6-9 below.

Table 6-9: MDH EUI adjustment for covered car park contribution

Total hospital energy use	**kWh**	63,214,892
Covered car park and substations area	**m^2**	70,740
EUI for carpark	**kWh/m^2.yr**	20
Total Energy use for car park	**kWh**	1,414,796
Remainder energy consumed for hospital blocks	**kWh**	61,800,096
Adjusted floor area	**m^2**	178,847
Adjusted EUI for hospital blocks	**kWh/m^2.yr**	**345.55**

This is still way below the good practice benchmark for this category building. Mater Dei is unique, and a lot of investment was made in its engineering services and architectural envelope when it was being built, as highlighted in section 4.4, to achieve a lot of energy saving features at very high costs. A few of these are the large number of chillers installed, each with no less than 8-eight-step control to match the hospital load exactly without wasting energy in a constant primary and variable secondary hydraulic system. This keeps the inertia of the primary circuits slightly above the secondary circuits for exact modular control, as shown in Figure 4-29. Another example is the installation of the 120 large air-handling units with energy recovery systems in a closed-window hospital policy. Also, energy efficiency is not only found in systems, which have the highest impact on the EUI but also in the building envelope. As already mentioned in Chapter 4, MDH has insulated double walls, double-glazed and shaded windows, insulated roofs and ceilings and overall, it has all the necessary features to make it efficient.

Now, the updated EUI for MDH (345.55 kWh/m².yr) is closer but still lower than the good practice benchmark (540kWh/m².yr), which shows that this hospital is energy efficient beyond the good practice level.

All in all, this part of the thesis has shown that the harmonised benchmarks for Malta, when compared to the actual EUIs are not only consistent but they are also *distinctively* representative of their categories, unlike the results that were achieved from the original SBEM-mt EPCs.

6.4 Summary

This chapter sought to compare the proposed good practice EUIs of Malta and those published for the UK for 29 categorised benchmarked buildings. It was found that these were very similar, notwithstanding the fact that the total degree days for Malta are lower than those of the UK by approximately 70%. This was attributed to the additional latent load for cooling, which almost counterbalances the heating demand needed for the UK. Some local building categories that require high ventilation rates were found to have higher EUIs than the corresponding ones in the UK database.

This study went on to compare the actual energy used on site for the three cluster buildings as illustrated in Chapter 4, with the calculated energy projections in the benchmarked buildings. The results showed that the EUIs for schools and the office revealed that these were of a typical construction and there is a potential for improving the energy efficiency status within them. On the other hand, the MDH was found to be highly efficient when compared to the good practice benchmark of its category. This agrees with the actual high efficiency building envelope, modern and efficient energy systems, and the optimum operation of this hospital.

7 CONCLUSION

7.1 Introduction

The research question aimed to investigate whether the non-residential energy performance certificates (EPCs), as issued by the national SBEM-mt software for Malta, are in line with the actual EUIs of different buildings. If not, then another solution would need to be devised that is transparent, reliable and repeatable.

The need to converge the EPC energy rating to actual EUI, is necessary to support Europe's efforts to achieve carbon neutrality by 2050. In order to accelerate this process, it is pertinent that the level of confidence in EPCs is enhanced, so investors can use them as a solid basis for taking energy efficiency investment decisions that will result in real savings in carbon emissions and energy expenditure.

The new update to the energy performance of buildings directive (EU) 2018/844 has emphasised that this energy performance gap will need to be addressed to achieve real carbon savings. New EN and ISO standards have been published that mostly focus on actual energy consumption in buildings, while the European Commission's main research funding programme *Horizon 2020* has dedicated significant funds to projects for studying next generation EPCs [47].

7.2 Research findings

The main research findings are chapter specific and can be summarised as follows:

1. The thesis found that there is a significant performance gap between EPC EUIs and the actual energy consumption measured on-site for three different representative clusters of non-residential buildings. Additionally, the performance gap is not consistent and varies on the positive and negative sides. On the other hand, the SBEM-mt classification was found to produce pessimistic class rating for well-designed and efficient buildings, which reduces confidence in its usefulness.

2. A change in direction was proposed and verified to present a methodology based on actual energy consumption and a tool was developed based on transparent scientific processes, to determine the EUIs for 29 different non-residential building categories. The tool's purpose was proved to produce good practice benchmarks for each of these categories.
3. The conversion of the UK 29 categorised benchmarks to their Maltese equivalent does not simply involve multiplying a factor, as evidently shown in Table 6-1. There are a multitude number of considerations to be made, such as the effects of: degree days; ventilation; latent load in the cooling mode; besides the weather-independent energy consumption that needs to be harmonised to local modes of construction.
4. This thesis is also showing that because of Malta's hot and humid weather in such a predominantly cooling load country, the EUIs for non-residential buildings are as high as other Northern predominantly heating European countries, such as the UK. As a result, the classification of Malta as a climate zone E country as recognised by the EU [19] may give a wrong indication on the amount of heating and cooling required and on the expected level of carbon dioxide emissions linked to that energy consumption. Instead, Malta should have been placed at the same level as the UK, i.e. Zone B. This could pave the way to have a more realistic review of Malta's commitment towards the reduction of carbon dioxide emissions and climate change.

7.3 Research impact

This research worked on the principle that energy consumption can be divided into weather-dependent and weather independent components. In this digital age, all non-residential buildings should consume similar amounts of weather-independent energy. This mainly depends on the type, class, design, occupation, use and maintenance irrespective in which country they are placed. While, the weather-dependent component is a function of the total degree days, ventilation rates and latent heat load in cooling mode.

This part of the EUI which is weather-dependent, changes direction from predominantly heating in the north of Europe to predominantly cooling in the south, such as for Malta. Once determined, the weather-independent component should be added to the weather-dependent component to determine the total EUI for that particular category of buildings. This principle made the following impacts:

7.3.1 Prediction of actual energy use.

This study has proposed a simple and direct methodology for determining the operational rating of non-residential buildings and comparing them to benchmarks developed within this thesis, all based on actual energy use readings, which can be taken from actual billings and real data collection meters.

The standardisation of building energy consumption benchmarks in energy use intensities considers all major factors such as building type, weather, size, operations, etc, to arrive to the most realistic and accurate consumption. As highlighted in section 2.5 by Sun Dongmei [76] by using a theoretical prediction type method or software to calculate the EUI, then multiple-regression analysis methods will need to be deployed. This requires a large number of input information from multitude non-residential buildings, each with different variables which is difficult to find in Malta or are not available at the time of writing. Besides the amount of data and workforce required, this methodology is time consuming and therefore is not sufficiently practical.

7.3.2 Lowering of energy use

As mentioned in Table 2-1 of section 2.1.4 of the literature review, non-residential buildings in Malta have the highest ratio of energy use from the total energy consumption in Malta, when compared to other European Member States. Considering that Malta is passing through challenging times where much-needed guidance on how to reach zero-energy use for new and renovated buildings can be best achieved, this thesis provides timely EUI benchmarks and knowledge that will positively contribute towards answering many frequently asked questions on the relevance of the EPCs for non-residential buildings. On the other hand, this research devised a methodology for the energy performance of non-residential buildings which is transparent, repeatable and reliable. This will give confidence to building owners, financers, and entrepreneurs to subscribe and invest in energy saving technology for which no cheap solution exists.

a) Transparent

The SBEM-mt EPCs of today are based on a black box approach and therefore the level of trust in these certificates is low. This is a common issue across many EU Member States. In order to overcome this barrier, the EPC needs to be more transparent. Other solutions, such as the one offered in this thesis is proposed for consideration in national implementation.

b) Repeatable

This methodology is repeatable, which means that when using the proposed methodology to find the EUIs for different buildings and comparing the relevant benchmarks, a well-designed building will consistently produce a good result close to the benchmark and a badly-designed and operated building will give poorer performance that is further away from the good practice benchmark.

c) Reliable

This methodology is reliable and is based on sound scientific evidence given that this method is actually designed in such a way that it depends on the actual energy consumption. The truth lies in a reality check derived from actual comparable measurements, therefore the actual average energy consumption over, e.g. three years should be sufficient to reflect this. On the other hand, if the energy use is reduced over the next three years, then one can carry out a new evaluation and produce a better energy rating for the building.

7.3.3 Benchmarks that stand the test of time

The proposed methodology and the determined 29 good practice benchmarks produce dynamic results. For example, if due to climate change the total degree days for Malta change over the next three years, then the methodology is sufficiently transparent to update all the benchmarks based on the more recent degree days readings. Likewise, if the energy consumption over three years of a building under study drops, then the actual energy consumptions for these years can be immediately utilised to update the energy rating of the building. Such a dynamic feature is very important for Malta to achieve real carbon neutrality by 2050, because both the benchmarks and the EUIs of non-residential buildings are based on real data that is constantly changing.

7.3.4 Predominantly Cooling Load Countries.

This thesis has shown that because of Malta's long hot and humid weather in such a predominantly cooling load country, the EUIs from the end-user point of view for non-residential buildings are as high as other Northern predominantly heating European countries such as the UK.

7.3.5 Energy Management Systems (EnMS)

The established 29 benchmarks can be used as reference for the first iteration of the initial audit procedure under the ISO 50001 Energy Management System (EnMS) standard, to establish the building's Energy Performance Indicators (EPIs). This will assist non-residential buildings in better management of their energy profile, thus improving their management strategies to increase energy efficiency, reduce costs, and improve environmental performance.

7.3.6 Number of Benchmarked buildings.

It is well known, all over Europe, that EPCs alone have not been effective in driving building renovations. Also, the low cost and time constraints often result in EPCs containing poorly tailored recommendations. Moreover, to date there are no official benchmarks set for non-residential buildings in Malta, except for offices and that is based on the SBEM-mt software[55], which has been shown to have serious limitations if used as a design tool. On the other hand, this study has produced 29 benchmarks covering all categories of non-residential buildings, which may serve as a reliable national benchmark database.

7.3.7 Complementing the Existing EPCs

This thesis is not suggesting that the asset rating is to be abolished, because the SBEM-mt EPC has the primary purpose of comparing the carbon emissions of an existing non-residential building to the same building had it been built according to the 2006 Minimum Energy Performance Technical Document F [131] with a 20% improvement. As mentioned in the SBEM-mt user manual, the software is not intended to be used for design or for optimising the building's energy efficiency options. Therefore, the ultimate use of the outcome of this research work is to complement and fill the missing gap of providing a means to measure the actual performance of a building and compare it to a best practice benchmark. Therefore, the results of this thesis can be utilised for policy making, to gradually achieve carbon neutrality through the identification of energy efficiency measures that have the highest impact. This is the recommended direction as amplified in the new EPBD (EU) 2018/884. In fact, as shown in Figure 2-13, out of the 27 Member States, 16 countries have already adopted some form of operational rating or are using it in parallel with the asset rating.

7.4 Study Limitations

This research work has encountered some limitations, which need to be addressed for future development:

a) There was a lack of well-designed operational buildings to be used as reference buildings for the 29 benchmarks. This is aggravated by the fact that the EPBD legislation is only mandatory for public authority buildings unless buildings are for sale or rented.

b) Since the national EPC data base is not accessible to the public or researchers this diminishes both access and transparency in the EPC procedures. Therefore, it was not possible to compare more EPCs of different categories to the proposed developed benchmarks.
c) The absence of sub-meters in non-residential buildings makes it difficult to aggregate energy consumption to the different energy sectors (space heating, space cooling, water heating, lighting, ventilation, equipment).
d) Malta was one of the first countries in Europe to adopt smart energy meters for electricity consumption from the grid. However, the interface between the end-user and energy smart meters is still missing. This hinders energy monitoring and does not encourage energy saving.

7.5 Recommendations for Future Research

This thesis has set the ground for future work in this area, which will support Malta's endeavours in curbing energy consumption and improving energy efficiency in non-residential buildings that so far lag behind in terms of incentives, support schemes or widespread campaigns for end-use energy efficiency. In order to achieve this, future research work is needed in the following areas:

a) Developing the proposed excel tool into a digital user-friendly format, which would enable assessors and energy experts to rate buildings, based on their operational energy consumption.
b) Similar to what was carried out in this thesis, more buildings from the identified clusters need to be tested using the proposed methodology to further confirm the validity of the proposed benchmarks for these other categories, such as restaurants, shops, hotels and residential homes.
c) The proposed benchmarks can also be fine-tuned to better fit the Maltese non-residential characteristics by verifying that the different services linked to the original categories apply to Malta. For example, in this research work, swimming pools were removed from the UK school's benchmark, given that their presence is rare in local schools. The weighted area average methodology can then be applied to further adapt

these benchmarks to the prevailing characteristics of Maltese non-dwelling categories.

d) Finally, it is proposed that the benchmarks are revised periodically, at least every 5 years, to advance their relevance and use stringent values for good practice benchmarks. This can be carried out by identifying high performing buildings and using their energy consumption to update the benchmarks, together with recent weather data to update the degree days of Malta.

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9 Appendices

1.1 Appendix A

TABLE 5-14: SUMMARY OF COOLING SPECIFIC LATENT LOAD FOR BENCHMARKED BUILDINGS

A	B	C	D	E	F	G	H	I	J	K	L	M	N	0	P	Q	R	S	T	U
Name and description		Allocation guides			Operating time				Internal Condition		Yearly latent load due to ventilation on cooling (kWh/ litre of ventilation air)				EN 6798	Floor space factors	Air flow per non-adapted person	Low Polluting Building	Total design ventilation rate	Total Q latent
Cat	Name	Space usage	Operational schedule	Reference hours per year	From	to	Days	Total hrs	DB ºC	RH %	2016	2017	2018	Yearly average	Cat	m² per person	l/s per person	l/(s.m²)	l/(s.m²)	kWh/m².yr
1	General office	Mainly by employees, for sedentary desk-based activities. Includes meeting and conference facilities.	Weekdays and early evenings	2040	8	17	5	9 hrs weekdays	23.5	50	13.48	10.79	17.47	13.91	III	6	4	0.4	1.07	**14.84**
2	High street agency	By employees mainly for desk-based activities and off-street visitors — public area and back office	Weekdays and early evenings, commonly part or all of weekend	2660	8	17	6	9 hrs weekdays plus 5 hrs sat	23.5	50	15.84	12.32	19.50	15.89	III	6	4	0.4	1.07	**16.95**
3	General retail	Mainly by clients, customers and visitors for a service activity; some facilities required for employees	Weekdays and early evenings, commonly part or all of weekend	2660	8	17	6	9 hrs weekdays plus 5 hrs sat	23.5	50	15.84	12.32	19.50	15.89	III	7	4	0.4	0.97	**15.43**
4	Large non-food shop	Mainly by customers for purchasing goods; some facilities required for employees	Typically week and weekend days	2660	8	17	6	9 hrs weekdays plus 5 hrs sat	23.5	50	15.84	12.32	19.50	15.89	III	7	4	0.4	0.97	**15.43**
5	Small food store	Mainly by customers for purchasing goods; some facilities required for employees	Typically week and weekend days	2660	8	17	6	9 hrs weekdays plus 5 hrs sat	23.5	50	15.84	12.32	19.50	15.89	III	7	4	0.4	0.97	**15.43**
6	Large food store	Mainly by customers for purchasing goods; some facilities required for employees	Typically week and weekend days; may be used in evenings; some are 24/7 operations	2860	8	17	7	9 hrs weekdays plus 5 hrs Sat & Sun	23.5	50	18.45	13.85	22.09	18.13	III	7	4	0.4	0.97	**17.61**
7	Restaurant	Storage and preparation of food which is then cooked and served to users; seating space for eating is provided	There is a wide variety of operational schedules, from selected portions of weekdays to 24/7 operation	3060	12	24	6	All days except Mon	23.5	50	26.72	21.20	28.68	25.54	III	5	4	0.4	1.20	**30.64**
8	Bar, pub or licensed club	Serving drinks and snacks, with standing and sitting areas for customers	Open to public or members, day and evening	3060	12	24	6	All days except Mon	23.5	50	26.72	21.20	28.68	25.54	III	4	4	0.4	1.40	**35.75**
9	Hotel	Primarily the provision of short-term accommodation and hygiene facilities	Primarily used in evenings and early morning	6560	14	7am	7	All days	24	50	35.28	34.65	42.45	37.46	III	8	4	0.4	0.90	**33.71**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	0	P	Q	R	S	T	U
10	**Cultural activities**	Spaces for displaying and viewing objects, with associated office and storage facilities	Daytime use, similar to office hours but more likely to be open on weekends	2040	8	17	5	9 hrs weekdays	23.5	50	13.48	10.79	17.47	13.91	III	5	4	0.4	1.20	**16.70**
11	**Entertainment halls**	Large assembly and seating areas, with associated ticketing and snack services, for performance events and films	Mainly in evenings, some daytime use. All days of week	2548	17	24	7	All days	23.5	50	19.34	17.69	22.58	19.87	III	5	4	0.4	1.20	**23.84**
12	**Swimming pool centre**	Swimming pool with associated facilities	Ranges from occasional use to daily and evening	2856	8	18	7	All days	25	60	6.96	8.02	8.00	7.66	III	5	4	0.4	1.20	**9.19**
13	**Fitness and health centre**	Fitness, aerobics, dance and solarium/sauna facilities	Typically daily and evenings	2754	10	20	7	All days	24	55	14.29	13.77	17.92	15.33	III	4	4	0.4	1.40	**21.46**
14	**Dry sports and leisure facility**	Dry sports and club house buildings — for a combined leisure centre include pool etc.	Ranges from occasional use to daily and evening	2754	10	20	7	All days	24	55	14.29	13.77	17.92	15.33	III	4	4	0.4	1.40	**21.46**
15	**Covered car park**	Provision for car parking and access	Weekday or 24-hour	4284	12	24	7	All days	Outside ambient	Outside ambient	0.00	0.00	0.00	0.00	III	6	4	0.4	1.07	**0.00**
16	**Public buildings with light usage**	Variety of facilities and services provided with generally public access when in use	Intermittent usage	2040	8	17	5	9 hrs weekdays	23.5	50	13.48	10.79		8.09	III	5	4	0.4	1.20	**9.71**
17	**Schools and seasonal public buildings**	Teaching and community activities	Weekday usage for part of the year	1400	8	14	5	9 hrs weekdays	23.5	50	10.89	8.69	10.74	10.11	III	5	4	0.4	1.20	**12.13**
18	**University campus**	Lecture theatres, offices, workshops, eating places, laboratories and other activities	Weekdays and evenings	2660	8	17	6	9 hrs weekdays plus 5 hrs Sat	23.5	50	15.84	12.32	19.50	15.89	III	5	4	0.4	1.20	**19.06**
19	**Clinic**	Provision of primary health care	Usually week days and early evenings	2040	8	17	5	9 hrs weekdays	23.5	50	13.48	10.79	17.47	13.91	I	8	10	1	2.25	**31.31**
20	**Hospital; clinical and research**	Mainly space for medical care with 24-hour accommodation for patients, with associated operating theatres, laboratories, offices and workshops	Continuous for the majority of the facility	8760	0	24	7	All days	24	50	45.28	40.35	54.34	46.66	I	8	10	1	2.25	**104.99**
21	**Long term residential**	Full accommodation, including sleeping space, day time space, all domestic facilities, some office facilities	Continuous	8760	0	24	7	All days	24	50	45.28	40.35	54.34	46.66	I	8	10	1	2.25	**104.99**
22	**General accommodation**	Space for sleeping, showers, basic domestic services	Non-continuous occupancy, often only used in evenings	2940	22pm	6am	7	All days	25	50	15.90	14.32	21.60	17.27	III	10	4	0.4	0.80	**13.82**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	0	P	Q	R	S	T	U
23	**Emergency services**	Offices, accommodation, food services, cells, garaging and other activities as required	Normally continuous, some stations closed in the evenings and weekends	8760	0	24	7	All days	24	50	45.28	40.35	54.34	46.66	I	8	10	1	2.25	**104.99**
24	**Laboratory or operating theatre**	Special equipment and conditions in at least 30% of floor area	Either weekday or 24-hour multi-shift	2040	8	17	5	9 hrs weekdays	23.5	50	13.48	10.79	17.47	13.91	I	8	10	1	2.25	**31.31**
25	**Public waiting or circulation**	Public circulation or waiting facilities	Variable — intermittent to continuous	2040	8	17	5	9 hrs weekdays	23.5	50	13.48	10.79	17.47	13.91	III	3	4	0.4	1.73	**24.12**
26	**Terminal**	Waiting and boarding facilities for air, ship or regional/international train travel	Daytime and evenings each day to near continuous	8760	0	24	7	All days	24	50	45.28	40.35	54.34	46.66	III	10	4	0.4	0.80	**37.33**
27	**Workshop**	Facilities for light mechanical work	Generally working week but can be multi-shift	2040	8	17	5	9 hrs weekdays	23.5	50	13.48	10.79	17.47	13.91	III	10	4	0.4	0.80	**11.13**
28	**Storage facility**	Storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2040	8	17	5	9 hrs weekdays	23.5	50	13.48	10.79	17.47	13.91	III	30	4	0.4	0.53	**7.42**
29	**Cold storage**	Refrigerated storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2660	8	17	6	9 hrs weekdays plus 5 hrs Sat	23.5	50	15.84	12.32	19.50	15.89	III	30	4	0.4	0.53	**8.47**

1.2 Appendix B

TABLE 5-17: HARMONISING UK WEATHER DEPENDENT EUIS TO MALTA WITH TOTAL DEGREE-DAYS

A	B	C	D	E	F	G	H	I	L	M	N	0	P	Q
Name and description		Allocation guides			Operating schedule				Total yearly DD for heating & cooling. Cooling DD harmonised during operation of main plant				Total UK EUIs for weather adjustment on 2021 DD	Malta EUIs DD weather adjusted
Cat	Name	Space usage	Operational schedule	Reference hours per year	From	to	Days	total hrs	2010	2016	2017	3 yearly average	($kWh/m^2.yr$)	(kWh/m^2 yr)
1	General office	Mainly by employees, for sedentary desk based activities. Includes meeting and conference facilities.	Weekdays and early evenings	2040	8	17	5	9 hrs weekdays	714	861	776	784	66.00	25.60
2	High street agency	By employees mainly for desk based activities and off street visitors — public area and back office	Weekdays and early evenings, commonly part or all of weekend	2660	8	17	6	9 hrs weekdays plus 5 hrs sat	798	934	854	862	28.00	11.94
3	General retail	Mainly by clients, customers and visitors for a service activity — some facilities required for employees	Weekdays and early evenings, commonly part or all of weekend	2660	8	17	6	9 hrs weekdays plus 5 hrs sat	798	934	854	862	24.75	10.56
4	Large non-food shop	Mainly by customers for purchasing goods — some facilities required for employees	Typically week and weekend days	2660	8	17	6	9 hrs weekdays plus 5 hrs sat	798	934	854	862	93.50	39.88
5	Small food store	Mainly by customers for purchasing goods — some facilities required for employees	Typically week and weekend days	2660	8	17	6	9 hrs weekdays plus 5 hrs sat	798	934	854	862	46.50	19.83
6	Large food store	Mainly by customers for purchasing goods — some facilities required for employees	Typically week and weekend days; may be used in evenings; some are 24/7 operations	2860	8	17	7	9 hrs weekdays plus 5 hrs sat & sun	879	1002	930	937	57.75	26.77
7	Restaurant	Storage and preparation of food which is then cooked and served to users; seating space for eating is provided	There is a wide variety of operational schedules, from selected portions of weekdays to 24/7 operation	3060	12	24	6	all days except Mon	714	1114	847	892	129.00	56.91
8	Bar, pub or licensed club	Serving drinks and snacks, with standing and sitting areas for customers	Open to public or members, day and evening	3060	12	24	6	all days except Mon	714	1114	847	892	140.00	61.76
9	Hotel	Primarily the provision of short term accommodation and hygiene facilities	Primarily used in evenings and early morning	6560	14	7	7	all days	714	1114	847	892	148.50	65.51

A	B	C	D	E	F	G	H	I	L	M	N	0	P	Q
Name and description		Allocation guides			operating time				Total yearly DD for heating & cooling. Cooling DD harmonised during operation of main plant				Total UK EUIs for weather adjustment on 2021 DD	Malta EUIs DD weather adjusted
Cat	Name	Space usage	Operational schedule	Reference hours per year	From	to	Days	total hrs	2010	2016	2017	3 yearly average	(kWh/m².yr)	(kWh/m² yr)
10	Cultural activities	Spaces for displaying and viewing objects, with associated office and storage facilities	Daytime use, similar to office hours but more likely to be open in weekends	2040	8	17	5	9 hrs weekdays	714	861	776	784	110.00	42.66
11	Entertainment halls	Large assembly and seating areas, with associated ticketing and snack services, for performance events and films	Mainly in evenings, some daytime use. All days of week	2548	17	24	7	all days	714	861	776	784	231.00	89.60
12	Swimming pool centre	Swimming pool with associated facilities	Ranges from occasional use to daily and evening	2856	8	18	7	all days	981	1187	981	1049	621.50	322.73
13	Fitness and health centre	Fitness, aerobics, dance and solarium/sauna facilities	Typically daily and evenings	2754	10	20	7	all days	1135	1047	788	990	176.00	86.20
14	Dry sports and leisure facility	Dry sports and club house buildings — for a combined leisure centre include pool etc.	Ranges from occasional use to daily and evening	2754	10	20	7	all days	1135	1047	788	990	181.50	88.89
15	Covered car park	Provision for car parking and access	Weekday or 24-hour	4284	12	24	7	all days	0	0	0	0	0.00	0.00
16	Public buildings with light usage	Variety of facilities and services provided with generally public access when in use	Intermittent usage	2040	8	17	5	9 hrs weekdays	714	861	776	784	57.75	22.40
17	Schools and seasonal public buildings	Teaching and community activities	Weekday usage for part of the year	1400	8	14	5	9 hrs weekdays	587	883	759	743	57.75	21.23
18	University campus	Lecture theatres, offices, workshops, eating places, laboratories and other activities	Weekdays and evenings	2660	8	17	6	9 hrs weekdays plus 5 hrs sat	798	934	854	862	132.00	56.30
19	Clinic	Provision of primary health care	Usually week days and early evenings	2040	8	17	5	9 hrs weekdays	714	861	776	784	110.00	42.66
20	Hospital; clinical and research	Mainly space for medical care with 24-hour accommodation for patients, with associated operating theatres, laboratories, offices and workshops	Continuous for the majority of the facility	8760	0	24	7	all days	1297	1473	1332	1367	231.00	156.28

Name and description		Allocation guides			Operating schedule				Total yearly DD for heating & cooling. Cooling DD harmonised during operation of main plant				Total UK EUIs for weather adjustment on 2021 DD	Malta EUIs DD weather adjusted
Cat	**Name**	**Space usage**	**Operational schedule**	**Reference hours per year**	**From**	**to**	**Days**	**total hrs**	**2010**	**2016**	**2017**	**3 yearly average**	**(kWh/m².yr)**	**(kWh/m² yr)**
24	**Laboratory or operating theatre**	Special equipment and conditions in at least 30% of floor area	Either weekday or 24-hour multi-shift	2040	8	17	5	9 hrs weekdays	714	861	776	784	88.00	34.13
25	**Public waiting or circulation**	Public circulation or waiting facilities	Variable — intermittent to continuous	2040	8	17	5	9 hrs weekdays	714	861	776	784	66.00	25.60
26	**Terminal**	Waiting and boarding facilities for air, ship or regional/international train travel	Daytime and evenings each day to near continuous	8760	0	24	7	all days	1297	1473	1332	1367	110.00	74.42
27	**Workshop**	Facilities for light mechanical work	Generally working week but can be multi-shift	2040	8	17	5	9 hrs weekdays	714	861	776	784	99.00	38.40
28	**Storage facility**	Storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2040	8	17	5	9 hrs weekdays	714	861	776	784	112.00	43.44
29	**Cold storage**	Refrigerated storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2660	8	17	6	9 hrs weekdays plus 5 hrs sat	798	934	854	862	44.00	18.77

1.3 Appendix C

TABLE 5-19: ADJUSTED NON-RESIDENTIAL ENERGY USE BENCHMARKS FOR NON-RESIDENTIAL BUILDINGS IN MALTA

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
	Name and description		Allocation guides				Further category details				Energy benchmarks for UK (kWh/m².yr)			Weather adjustment			Weather adjusted for Malta (kWh/m².yr)			Benchmark for Malta
Cat	Name	Brief description	Space usage	Operational schedule	Reference hours per year	Distinguishing features	Services included	May be part of mixed use with areas below	Summary of allowable special energy uses	Representative buildings	Electricity typical benchmark	Fossil-thermal typical benchmark	Total	Percent of electricity benchmark pro-rated to degree-days	Percent of fossil-thermal benchmark pro-rated to degree-days	Total for weather adjustment of 2021 DD	Adjusted Malta TDD when cooling plant is on	Q_{latent} due to ventilation on cooling	Total energy due to weather	Total Energy usage per unit area (kWh/m².yr)
1	**General office**	General office and commercial working areas	Mainly by employees, for sedentary desk-based activities. Includes meeting and conference facilities.	Weekdays and early evenings	2040	Relative uniformity of occupancy, density, conditions, schedule and appliances	Heating, lighting, cooling, employee appliances, standard IT, basic tea room	Covered car park, staff restaurant	Regional server room, trading floor	General office benchmark category for all offices whether air conditioned or not, Town Halls, architects, various business services that do not include retail functions	95	120	**215**	0%	55%	66.00	25.60	14.84	40.44	**189**
2	**High street agency**	High street agency	By employees mainly for desk-based activities and off-street visitors — public area and back office	Weekdays and early evenings, commonly part or all of weekend	2660	Office type of activities, with retail street frontage, and consequent infiltration and glazing losses	Heating, lighting, cooling, employee appliances, standard IT, basic tea room			Bank branches, estate agents, travel agents, legal, insurance and advertising services, off-street professional services, post offices, betting shops	140	0	**140**	20%	0%	28.00	11.94	16.95	28.89	**141**
3	**General retail**	General street retail and services	Mainly by clients, customers and visitors for a service activity — some facilities required for employees	Weekdays and early evenings, commonly part or all of weekend	2660	Basic heating, lighting, cooling for off-street premises that may contain a wide variety of activities besides sale of goods	Heating, lighting, cooling, appliances for small number of employees			High street store or local stores. Corner shops, amusement arcades, takeaways, hairdressers, laundries, laundrettes, dry cleaners, hire premises, indoor markets	165	0	**165**	15%	0%	24.75	10.56	15.43	25.99	**166**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
4	**Large non-food shop**	Retail warehouse or other large non-food store	Mainly by customers for purchasing goods; some facilities required for employees	Typically week and weekend days	2660	Large, and tends to be solely used for retailing	Heating, lighting, cooling, appliances for small number of employees			Retail warehouses or shed, department stores, hypermarkets, large showrooms	70	170	**240**	0%	55%	93.50	39.88	15.43	55.31	**202**
5	**Small food store**	Small food store	Mainly by customers for purchasing goods; some facilities required for employees	Typically week and weekend days	2660	Greater needs for refrigeration of goods than other shops	Heating, lighting, display cabinets, food storage, employee appliances			Food stores, green grocers, fish shops, butchers, delicatessens	310	0	**310**	15%	0%	46.50	19.83	15.43	35.26	**299**
6	**Large food store**	Supermarket or other large food store	Mainly by customers for purchasing goods; some facilities required for employees	Typically week and weekend days; may be used in evenings; some are 24/7 operations	2860	Greater needs for refrigeration of goods, and larger, than other shops	Heating, lighting, display cabinets, food storage, employee appliances	Covered car park	Bakery oven	Supermarkets and freezer centres	400	105	**505**	0%	55%	57.75	26.77	17.61	44.38	**492**
7	**Restaurant**	Restaurant	Storage and preparation of food which is then cooked and served to users; seating space for eating is provided	There is a wide variety of operational schedules, from selected portions of weekdays to 24/7 operation	3060	Assumes minimal reheat of food.	Heating, lighting, cooling, food storage, heating of pre-prepared food		Cooking equipme nt in a catering kitchen	Cafes, restaurants, canteens, refectories, mess halls	90	370	**460**	20%	30%	129.00	56.91	30.64	87.55	**419**
8	**Bar, pub or licensed club**	Bar, pub or club	Serving drinks and snacks, with standing and sitting areas for customers	Open to public or members, day and evening	3060	Major activity is the bar and associated areas	Heating, lighting, cooling, some office appliances, snack provision			Pubs licensed clubs, members clubs, wine bars	130	350	**480**	0%	40%	140.00	61.76	35.75	97.51	**438**
9	**Hotel**	Hotel or boarding house	Primarily the provision of short-term accommodation and hygiene facilities	Primarily used in evenings	6560	Provision for paid short term accommodatio n	Heating, lighting, cooling, some office appliances, laundry services	Swimming pool, fitness and health centre, restaurant, general office (for conferenc e facility)		All hotel types, guest houses, motels	105	330	**435**	0%	45%	148.50	65.51	33.71	99.23	**386**
10	**Cultural activities**	Museum, art gallery or other public building with normal occupancy	Spaces for displaying and viewing objects, with associated office and storage facilities	Daytime use, similar to office hours but more likely to be open in weekends	2040	Activity is office-like in its requirements with additional conditioning requirements for display and storage of artefacts	Heating, lighting, cooling, humidity control			Municipal museums, libraries and galleries, higher education arts buildings	70	200	**270**	0%	55%	110.00	42.66	16.70	59.36	**219**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
11	**Entertainment halls**	Entertainment halls	Large assembly and seating areas, with associated ticketing and snack services, for performance events and films	Mainly in evenings, some daytime use. All days of week	2548	Tend to be large halls, mainly used in evenings	Heating, lighting, cooling of main entertainment spaces, and circulation. Ticketing and snacks provision			Cinemas, theatres, concert halls. Bingo halls	150	420	**570**	0%	55%	231.00	89.60	23.84	113.44	**452**
12	**Swimming pool centre**	Swimming pool hall, changing and ancillaries	Swimming pool with associated facilities	Ranges from occasional use to daily and evening	2856	Pool hall is the dominant space use — may have small café and fitness room	Heating, lighting, cooling of all spaces. Office appliances, showers, snack provision and bar			Swimming pool centre without further sports facilities	245	1130	**1375**	0%	55%	621.50	322.73	9.19	331.92	**1085**
13	**Fitness and health centre**	Fitness centre	Fitness, aerobics, dance and solarium/sauna facilities	Typically daily and evenings	2754	Provision of sports and entertainment equipment with generally high energy usage, and internal gains	Heating, lighting, cooling of all spaces. Office appliances, showers, snackprovision and bar			Fitness centre, health centre	160	440	**600**	0%	40%	176.00	86.20	21.46	107.65	**532**
14	**Dry sports and leisure facility**	Dry sports and leisure facility	Dry sports and club house buildings — for a combined leisure centre include pool etc.	Ranges from occasional use to daily and evening	2754	Provision of space to support separated sporting and entertainment activities often lightly serviced	Heating, lighting and basic office equipment	Swimming pool, fitness and health centre	Sports flood lighting	Dry sports halls, sports grounds with changing rooms, tennis courts with office, speedway tracks, stadiums, pavilions	95	330	**425**	0%	55%	181.50	88.89	21.46	110.35	**354**
15	**Covered car park**	Car park with roof and side walls	Provision for car parking and access	Weekday or 24-hour	4284	Lighting and mechanical ventilation when in use.	Lighting and ventilation	Office, public building in central urban location	Lighting and ventilation	Office, public building in central urban location	20	0	**20**	0%	0%	0.00	0.00	0.00	0.00	**20**
16	**Public buildings with light usage**	Light use public and institutional buildings	Variety of facilities and services provided with generally public access when in use	Intermittent usage	2040	Lightly serviced or lightly used	Heating and lighting				20	105	**125**	0%	55%	57.75	22.40	9.71	32.11	**99**
17	**Schools and seasonal public buildings**	Public buildings nominally used for part of the year	Teaching and community activities	Weekday usage for part of the year	1400	Public buildings with part annual occupancy	Heating, lighting and basic office equipment, teaching equipment, computers	Restaurant (dining hall)		Primary and secondary schools, nurseries, creches, youth centres and community centres	36	105	**141**	0%	55%	57.75	21.23	12.13	33.36	**117**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
18	**University campus**	University campus	Lecture theatres, offices, workshops, eating places, laboratories and other activities	Weekdays and evenings	2660	Large floor space and variety of activities	Heating, lighting, cooling, office and teaching equipment	Laboratory, restaurant	Furnace or forming process	Typical campus mix for further and higher education universities and colleges	80	240	**320**	0%	55%	132.00	56.30	19.06	75.36	**263**
19	**Clinic**	Health centres, clinics and surgeries	Provision of primary health care	Usually week days and early evenings	2040	Daytime use, essentially office hours, but needs to provide for high public use, generally by appointment	Heating, lighting, cooling, hot water services			Doctors surgeries, health clinics, veterinary surgeries, dentist	70	200	**270**	0%	55%	110.00	42.66	31.31	73.97	**234**
20	**Hospital; clinical and research**	Clinical and research hospital	Mainly space for medical care with 24-hour accommodation for patients, with associated operating theatres, laboratories, offices and workshops	Continuous for the majority of the facility	8760	24-hour accommodation with stringent environmental conditions, ventilation control, quarantine, and high occupant servicing needs	All services	Laboratory or operating theatre, restaurant	Furnace or forming process	Acute hospital, specialist hospital, teaching hospital and maternity hospital	90	420	**510**	0%	55%	231.00	156.28	104.99	261.27	**540**
21	**Long term residential**	Long term residential accommodation	Full accommodation, including sleeping space, day time space, all domestic facilities, some office facilities	Continuous	8760	24-hour fully conditioned and serviced accommodation	Heating, lighting, cooling, appliances, food and hot water services, entertainment, laundry	Restaurant (dining hall)		Residential home, homeless unit, cottage hospital and long stay hospital, detention centres and prisons	65	420	**485**	0%	55%	231.00	156.28	104.99	261.27	**515**
22	**General accommodation**	General accommodation	Space for sleeping, showers, basic domestic services	Non-continuous occupancy, often only used in evenings	2940	Slow turnover of occupants requires fewer facilities and less laundry than for example a hotel	Heating, lighting, cooling, laundry and drying rooms			Boarding houses, university and school hostels, homeless units, nursing homes	60	300	**360**	0%	55%	165.00	68.72	13.82	82.54	**278**
23	**Emergency services**	Emergency services	Offices, accommodation, food services, cells, garaging and other activities as required	Normally continuous, some stations closed in the evenings and weekends	8760	Provision of a variety of services that would be in separate categories in other parts of the non-domestic stock (e.g. accommodation, offices and vehicle garaging)	Heating, lighting, cooling, food services, office and training equipment			Police, fire and ambulance stations	70	390	**460**	0%	55%	214.50	145.12	104.99	250.10	**496**
24	**Laboratory or operating theatre**	Laboratory or operating theatre	Special equipment and conditions in at least 30% of floor area	Either weekday or 24-hour multi-shift	2040	Spaces requiring controlled ventilation and conditions	Heating lighting, ventilation		Furnace or forming process	Research chemical laboratory, hospital	160	160	**320**	0%	55%	88.00	34.13	31.31	65.44	**297**

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
										operating theatre										
25	**Public waiting or circulation**	Bus or train station, shopping centre mall	Public circulation or waiting facilities	Variable — intermittent to continuous	2040	Waiting and circulation areas, booking desks, boarding facilities	Heating, lighting, cooling, snack services	Retail		Bus stations, local train stations, shopping centre malls	30	120	**150**	0%	55%	66.00	25.60	24.12	49.72	**134**
26	**Terminal**	Regional transport terminal with concourse	Waiting and boarding facilities for air, ship or regional/international train travel	Daytime and evenings each day to near continuous	8760	Concourse areas, booking areas, identification, customs, security and baggage handling	Heating, lighting, cooling, baggage handlings	Retail, restaurant, covered car park		Large train stations, airport terminals	75	200	**275**	0%	55%	110.00	74.42	37.33	111.75	**277**
27	**Workshop**	Workshop or open working area (not office)	Facilities for light mechanical work	Generally working week but can be multi-shift	2040	Goods access, mechanical tools and facilities	Industrial heating and lighting standards		Furnace or forming process	Workshops, vehicle repair	35	180	**215**	0%	55%	99.00	38.40	11.13	49.53	**166**
28	**Storage facility**	Storage warehouse or depot	Storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2040	Lightly serviced long term storage areas	Low level lighting and heating in storage areas			Distribution warehouse without public areas, and local authority depot	35	160	**195**	0%	70%	112.00	43.44	7.42	50.86	**134**
29	**Cold storage**	Refrigerated warehouse	Refrigerated storage and goods handling areas	Continuous storage with weekday or multi-shift goods handling	2660	Refrigerated long term storage areas	Refrigeration, lighting and heating of handling areas		Blast chilling or freezing plant	Refrigerated warehouse without public areas	145	80	**225**	0%	55%	44.00	18.77	8.47	27.24	**208**

1.4 Appendix D

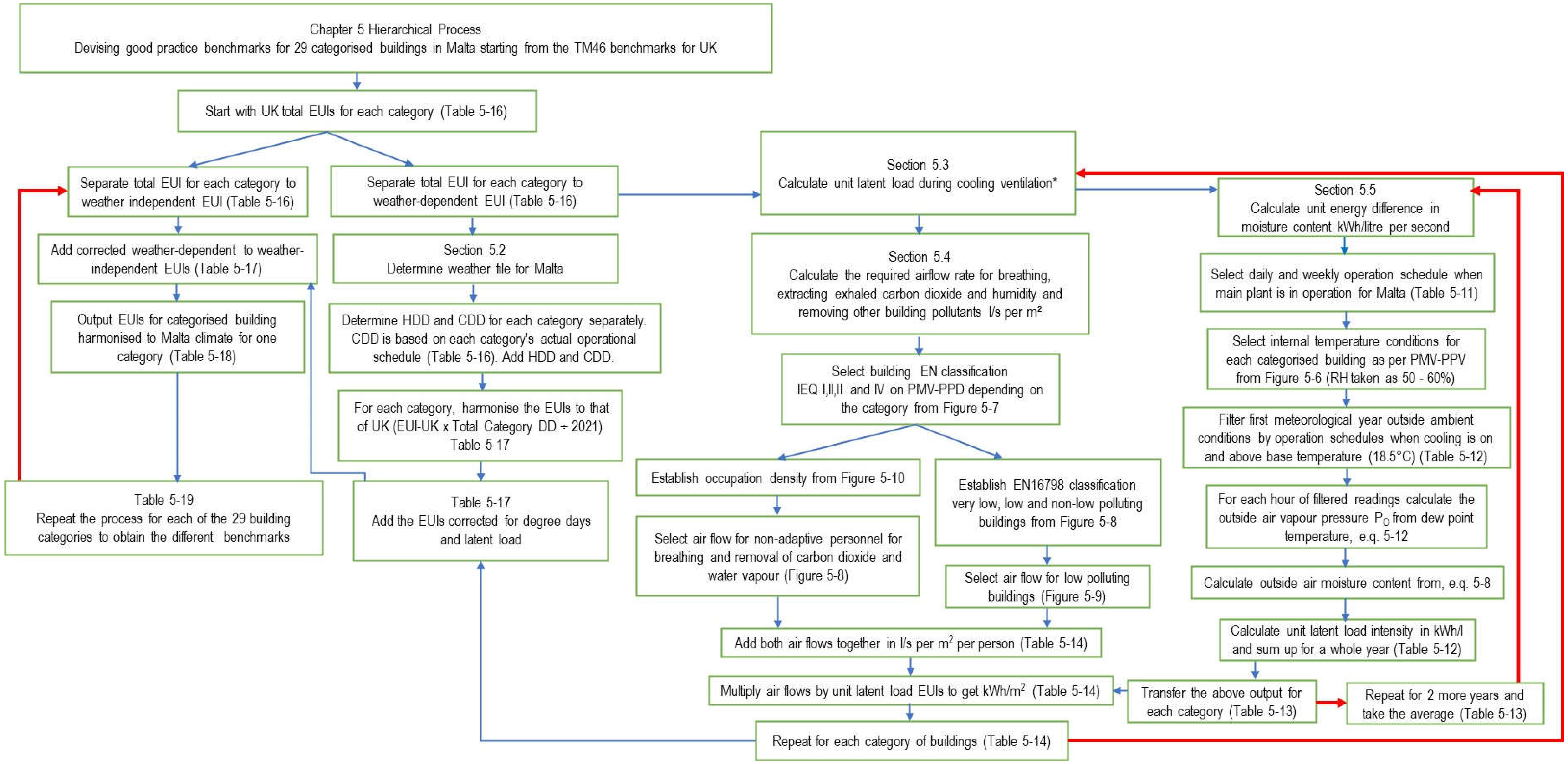

Figure 5-2: Flow chart showing the template that has been devised to determine good practice benchmarks for Malta