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PERFORMANCE GAP BETWEEN ASSET AND OPERATIONAL ENERGY PERFORMANCE RATING FOR NON-RESIDENTIAL BUILDINGS

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ABSTRACT: This paper aims at identifying anomalies that may exist when an asset rating is compared to the actual energy consumption of a non-residential building. This study is part of an on-going Ph.D. study focusing on the performance gap phenomena between energy consumption and energy modelling using standardized energy performance software. As a first stage, it is important to identify the extent of this gap by studying various local non-residential projects with EPCs, as calculated by the Simplified Building Energy Model for Malta (SBEMmt).

Discrepancies have been identified for two buildings (a large hospital and a large office building). A first approach for solving such discrepancies have been made to change or enhance the status quo, so that the EPC would become more meaningful for our local situation and for developing energy efficient buildings in the future. The peculiarity of Malta as being predominately cooling will be highlighted and contrasted.

Keywords: Energy Performance Gap, Layout, EPC, SBEM-mt 4.2c

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1 INTRODUCTION

As requested by the EU Energy Performance of Building Directive (EPBD), which was transposed into national legislation by Legal Notice LN 376/2012 [1] and its recent update LN 47/2018 [2], Energy Performance Certificates (EPCs) are required when a building is built, renovated, sold or rented. This is done to provide the energy performance and carbon emission ratings, as well as recommendations for improving the energy performance of the building.

These EPCs are produced using standard methods and assumptions about energy use to enable the comparison of energy performance rating of buildings of the same type to each other, as well as to have a benchmark of the building in relation to the same construction had it been built according to the minimum energy performance requirements as set in Technical Document F. The EPC is valid for ten years but must be reviewed if modifications to the property are made within this period.

Energy consumption forecasting is a critical and necessary input to planning and controlling energy usage in the building sector, which accounts for 40% of the world's energy use and the world's greatest fraction of greenhouse gas emissions [3]. However, due to the diversity and complexity of buildings, as well as the random nature of weather conditions, energy consumption and their probabilistic behaviour are difficult to predict, especially in non – residential buildings.

The National Calculation Method (NCM) - SBEMmt. v4.2c, is the only recognised software that can generate energy performance certificates for non-residential buildings in Malta. As such EPCs for non-residential buildings are calculated using the Simplified Building Energy Model for Malta (SBEMmt.4.2c) [4], [5], which was developed by the BRE in the UK and adapted to Malta's local weather climate data file. This software models the building using relatively simple algorithms, based on monthly averages that take into account:

a) Standard indoor set temperature conditions, occupancy, and schedules;
b) Position and orientation of the structure;
c) Building fabric characteristics;

d) Heating, ventilation, and air-conditioning (HVAC) features;
e) Domestic hot water (DHW);
f) Lighting and daylighting;
g) Passive design features;
h) Selected renewables, other power co-generation options (CHP) and heat recovery.

The software calculates what is known as the Building Emission Rating (BER) regarding CO_2 discharge to the atmosphere, using the appropriate set primary energy carbon emissions factors. For electrical generation, the carbon emission factor for the SBEM v4.2c is set at 0.878 kg/kWh [6]. However, one notes that following the significant upgrade to the power generation facilities in Malta, by the use of liquefied natural gas and the commissioning of the electric interconnector between Malta and Sicily, the overall primary to electrical energy factor is being proposed to drop to 2 instead of 3.45, which is used in SBEM-mt [6]. This would imply that the carbon emission factor would be closer to 0.51 and would eventually call for a future upgrade of the software inbuilt values.

At the same time, to calculate what is known as the Standard Emission Rate (SER), the software works out the carbon emissions resulting from the use of a virtual reference building had it been built according to the old Technical Document F (2006) [7], plus an improvement factor of 20%, The Reference Building is considered as:

a) Having the same size and shape of the actual building (but glazing area depends on the set minimum energy requirements);
b) Each space contains same activity as the building under consideration, and therefore activity schedules, including set point temperatures and other parameters are as actual;
c) Same orientation and weather data file;
d) Building envelope U-values set as in Technical Document F (2006 version);
e) Space heating and cooling (cooling only when needed to avoid overheating at temperatures above 26.5 °C).

In the process, once the building emission rating (BER) and the improved standard (SER) are established, the software compares the BER to the SER and gives an Energy Performance Certificate Rating (EPC), which is characterised by a number and a letter, depending on where that number lies within the set letter bands. The letters range from A to G, each one comprising of 50 points (e.g., Letter A is for EPC between 0 and 50)

The rating is calculated on the performance of the building’s geometry and its building services (such as cooling, heating, ventilation, water heating, lighting, and renewables). It does not consider any plug-in loads, electronic appliances or white goods, as required by the EPBD methodology. This is known as an asset rating (AR) - that is, how energy efficient the building has been designed and constructed.

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 of what one may call as "gap" or discrepancy may be an essential factor that affects the decision of landlords, entrepreneurs or their advisors on the need to invest in improvements, as proposed in any EPC.

As such typical functional buildings in Malta were studied by having their EPCs as specifically generated or as produced by registered assessors and compared to the actual annual energy usage on site at that time.

For this exercise three types of non-residential buildings were identified and studied, with each cluster related to their building complexity namely:

- **Cluster Type 1:** elementary non-residential buildings, which are nearly free-running buildings or are very similar in the fabric to domestic premises and services present, such as schools or a block of shops with say flats or apartments above them.
- **Cluster Type 2:** non-residential buildings, where comfort conditions need to be controlled utilizing “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 plus artificial lighting. Offices and restaurants fall under this cluster type definition.
- **Cluster Type 3:** are 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, and other extensive amenities.

This paper will study one example of the type Cluster 2 and Cluster 3, as explained above.

2 CLUSTER TYPE 2 PERFORMANCE GAP

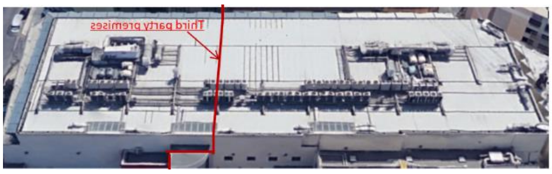
2.1 The Building Envelope

The office building was constructed in the early 2000s and is mainly located in a semi-industrial zone with a modern style of architectural features, in a practically unshaded development. The plan has a rectangular shape and has about one-third of its internal area shared with another business firm having a separate entrance, permanent dividing walls, and systems and metering as different tenants.

The building is a two-floor block measuring circa 65m x 34m built on a slope along its short axis on top of a carpark for firm's employees. The carpark also houses the main Enemalta power incomer cables and the main electrical switchgear panels with metering sections. The carpark is managed as a separate entity and as such was not considered as part of this study.

Nearly all the HVAC plant is installed exposed on the roof as shown in Figure 1. This building is mainly used for active day-to-day business interaction with the general public, as well as back-end administrative activities, all operating within a pleasant modern environment with closed window policy setup. The first floor is accessible by an external lift and stairs near the main entrance and two more lifts within the building.

Figure 1: Plan view of building



This building may be categorized as a heavy construction built on reinforced concrete columns and beams with peripherals in double layer walls of 150 mm thick block concrete with 50 mm 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 1 below.

Table 1: schedule of building material used.

Item	Type	Density	U- Value	Thermal mass
		kg/m^2	W/m^{2}K	kJ/m^{2}K
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 partitions	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 concreate + 80mm Torba + 80mm Screed + WP membrane	764.82	0.87	4.73
Ground Floor Slab	Tile + 80mmTorba+ 225mm Cast concrete	703.50	1.99	108.43
First Floor Slab	Tile + 80mmTorba+ 225mm Cast concrete+ void + soffit tile	709.62	0.94	103.88
Ceiling on Ground	19mm Soffit tile + void + 225mm cast concreate + 80mm Torba + 25mm tile	709.62	0.93	4.73
Glazing	Aluminuim 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	-

2.2 The Engineering System

2.2.1 Air conditioning

Both floors of this building are air-conditioned by 16No 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 centralized 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.

2.2.2 Ventilation

All areas are positively ventilated by 19No 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.

Similarly, all restrooms, changing rooms and ablutions are negatively ventilated through 4No inline duct mounted centrifugal fans with ceiling mounted extract grilles for a total extract air of 4,200 m^3//hour. As a result, there is overall positive pressurization of around 10,800 m^3/hour of excess treated air, which usually finds its way to the outside through exfiltration, when doors are opened.

2.2.3 Domestic hot water system (DHWS)

Domestic hot water is provided by 4No independent and dedicated electric hot water boilers of different capacities, ranging between 20 and 50 litres, which serve sanitary ware in a single pipe configuration, but with no return pipework.

2.2.4 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, whilst 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, with manual switching in all other areas but no occupancy sensors.

2.3 SBEM-mt input data and rating

2.3.1 Geometry

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 and inputted into the building geometry information tab as requested by SBEM-mt. Figure 2 shows the zoning of the ground floor, whereby all rules were adhered to in determining each zone characteristics.

2.3.2 Building services

Once the building geometry data was completed and inputted in SBEM, the information on the building services installed was gathered and inputted in the appropriate building service tabs in global or zonal configurations. 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 pressurization, and specific fans power (SFP)
- HWS systems – including information on the type and capacity of hot water systems in the building
- Lighting systems – a lighting design had been done 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.

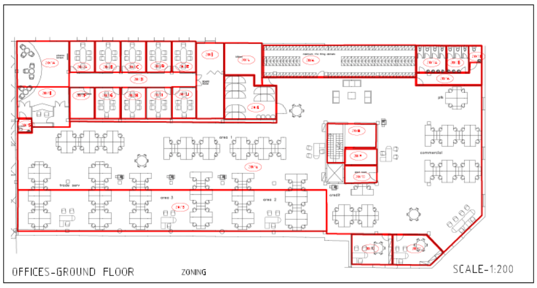
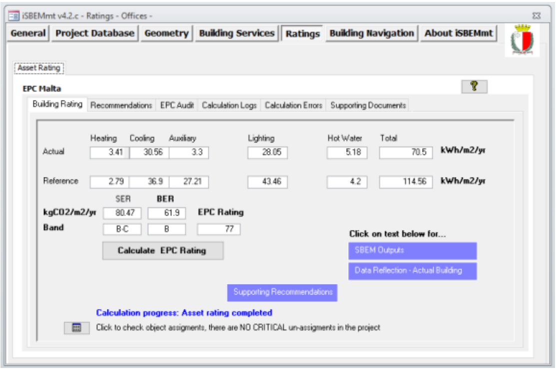


Figure 2: Ground floor zoning.

2.4 SBEM Rating Results

Once all the geometry and building services data was inputted, the energy performance rating of the building was calculated using the rating tab. This gave a very conservative total annual energy consumption of 70.5 kWh/m^2. Consisting of yearly consumption of 3.41 kWh/m^2/year for heating; 20.56 for cooling; 3.3 for auxiliaries; 28.05 for lighting and 5.18 kWh/m^2/year for domestic hot water all as shown in Figure 3.



	Heating	Cooling	Auxiliary	Lighting	Hot Water	Total	
Actual	3.41	30.56	3.3	28.05	5.18	70.5	kWh/m2/yr
Reference	2.79	36.9	27.21	43.46	4.2	114.56	kWh/m2/yr

	SER	BER	EPC Rating
kgCO2/m2/yr	80.47	61.9	
Band	B-C	B	77

Calculation progress: Asset rating completed

Click to check object assigments, there are NO CRITICAL un-assigments in the project

Figure 3: Unit and annual energy consumption for each service, as produced by SBEM-mt.

Figure 4 shows the final outcome of the EPC, where sector-specific energy consumption is depicted, as well as the percentage contribution of the total energy consumption. When projected to primary energy use this rating reflected a unit annual CO_2 emittance into the atmosphere of 61.9 kg/m^2 per year, which translates to an improvement around 15.6 % thus attaining a grade B.

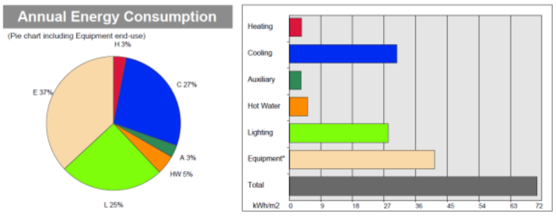


Figure 4: SBEM-mt rating results.

2.5 Actual Measured Energy Consumption

Central electrical energy is taken from two motor control centers 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 only deals with the energy required for cooling, heating, ventilation, domestic hot water services and lighting, one has to compare like with like and therefore it was essential to extract the same information from the overall energy consumption. With regards to the VRF outdoor units, this was continuously being metered and it was possible to extract the data for the years 2011 through 2017, as shown in Table 2 below.

Table 2: Yearly metered energy consumption by the VRF outdoor units

Metered & actual Energy Consumption	kWh per year						
Year	2011	2012	2013	2014	2015	2016	2017
Ground Floor VRF out door units	73,853	79,316	76,262	73,622	87,274	91,741	88,492
First Floor VRF out door 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, fans and lighting had to be obtained through analytical calculations, based on an indication of the absorbed power multiplied by an indication of the daily number of hours of operation.

In such case, the energy absorbed by the 105No VRF cassette indoor units each having a 70/60W motor fed from 16No separate small power circuits operating for 9 hours per day and 6 hours on Saturdays' on time controlled schedule (2652 hours per year) amounted to a total of 16,708 kWh per year.

Similarly, each of the 9No individual split air-conditioners i.e. AC 1 to AC9 had their annul energy consumption calculated by dividing their nominal cooling capacity of each unit by the COP to get the maximum absorbed power and then multiplied by the daily number of operating hours to a total of 142,957 kWh/yr.

However, in this case and in view that the energy absorbed by buildings in a place such as Malta with high solar radiation can be taken to vary daily, monthly and yearly quasi-sinusoidal [8], [9], a root mean square factor (RMS) of 0.55 of the maximum value was taken to give a more conservative energy consumption approach. This amounted to a total annual energy consumption of 78,627 kWh.

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 19,829 kWh and 10,464 kWh, respectively.

Also, for lighting, a full survey report of all lighting fixtures was used together with the scheduling programme for each luminaire or group of luminaires, to arrive at the actual energy consumption of 9,763 kWh per year.

For the unit annual energy consumption these were all added up and divided by the total zones area. In fact the 7 yearly unit mean 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 113.02 to 118.42 kWh/m^2 per year, as shown in Table 3 below.

Table 3: Summary of measured and actual energy consumption on site for respective services

Metered & Actual Energy Consumption	kWh per year							
Year	2011	2012	2013	2014	2015	2016	2017	**Average kWh/m^2 yr**
Ground Floor VRF out door units	73,853	79,316	76,262	73,622	87,274	91,741	88,492	
First Floor VRF out door 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	**47.87**
Indoor VRF units	16,708	16,708	16,708	16,708	16,708	16,708	16,708	**5.26**
AC units split	78,627	78,627	78,627	78,627	78,627	78,627	78,627	**24.77**
Ventilation Fans	19,829	19,829	19,829	19,829	19,829	19,829	19,829	**6.25**
DHW	10,464	10,464	10,464	10,464	10,464	10,464	10,464	**3.30**
Lighting	89,763	89,763	89,763	89,763	89,763	89,763	89,763	**28.28**
Total actual	215,390	215,390	215,390	215,390	215,390	215,390	215,390	**115.72**
Total Measured & actual 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**							

2.6 Gap Analysis for Cluster Type 2 Building

The measured and actual calculated readings were plotted and compared against the rating values as generated by SBEM and as shown in Figure 5 below. From the graph it is evidently 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 to that actually as measured. This amounts to nearly 60 to 67% with SBEM being so much in underestimation.

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 energy consumption of the HVAC systems, which was more than double to that predicted, as shown in Table 4 below.

The mismatch is so large that even when adding together SBEM yearly prediction for heating, cooling and auxiliaries (ventilation) at 37.72 kWh/m², this could not even match the measured unit load of the VRF outdoor unit alone at 47.87 kWh/m², as shown in Table 3 above. Notwithstanding that the complete HVAC system consists of more equipment than just the VRFs outdoors. Namely, the energy consumed by the indoor units, individual split units, and ventilation fans.

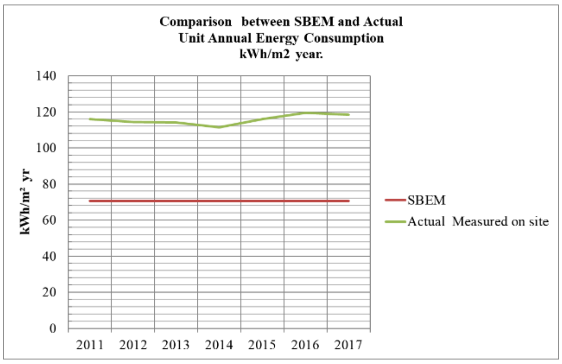


Figure 5: Graphical comparison of energy consumption as projected by SBEM to that measured

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

Unit Annual Energy Consumption	**Average kWh/m^2 yr.**		**Precentage Rating by SBEM as comapred to actual**	
System	**SBEM**	**Measured & Actual**		
heating	3.41	77.91	-229.34%	under
cooling	30.56			
Auxiliary	3.3	6.25	-89.28%	under
Lighting	28.05	28.28	-0.81%	under
hot water	5.18	3.30	36.37%	over
Total	70.5	115.72	-64.15%	under

2.3.6 Discussion

In a predominantly warm country like Malta, this mismatch may all be related to the way cooling load is calculated for which the SBEM uses the Admittance Method [10]. One needs to understand that a cooling load must take into account heat gain into space from outdoors, as well as 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, all with widely differing thermo-physical properties.
- The geometrical relationships between many building components are complex.
- 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 transient rather than steady-state.
- Most of the heat transfer processes in a building are interrelated.

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 the known as the Sol-Air temperatures on exposed surfaces, which then uses the principle of superposition to sum the effects of the individual heat gains [11]. This procedure requires a lot of pre-determined complex data from actual buildings and resulting in the calculation of three other parameters besides the widely used thermal transmittance (U-Value), such as the admittance, surface factors, and decrement factors [10]. These parameters depend upon the thickness, thermal conductivity, 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 to form weighted factors.

As for the winter heating, personal experience in working and designing such large modern open-plan offices with a lot of computers and peripherals, it is amply clear that SBEM may be over-rating the heating demand. This was also proven by on site observations since the operation and maintenance personnel confirmed that in winter the air-conditioning systems are either switched off or put on an intermittent cooling mode operation by the floor managers. As otherwise, there would be the likelihood of complains by the employees of over-heating.

Even this is to be expected and can be proven such that when one calculates the number of heating degree days (HDD) for the last 3 years, as reported by an internationally approved degree day weather calculator BizEE software [12] for a standard base temperature of 15.5 °C, Malta’s average heating degree days (HDD) per year is only 351 This is rather low, when compared to other cities such as London, which has 2,500 HDD.

One has also to consider that the standard base temperature of 15.5 °C (which is that temperature for which the building will require no heating or cooling as the effect of outside solar, inside activities and equipment heat gains will more than offset off-set the heat loss through conduction and infiltration) is rather high for Malta’s climate, as the effect of solar gain is predominant. In view of Malta’s position on the globe, the direct and diffuse radiation even in January reaches above 2,500 Wh/m².day on a horizontal surface, as shown in Figure 6 [8].

As such and from experience, one should consider lowering the base temperature for such buildings to around 13 °C, for which the number of heating degree days will be substantially lower and would most likely occur at times outside the regular office hours (08:00 – 17:000, as shown in red curve (noon) in Figure 7 below [9].

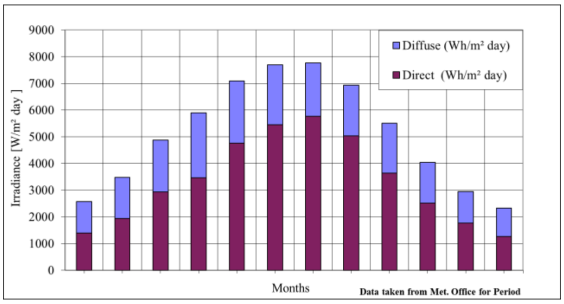


Figure 6: Mean daily solar radiation on a horizontal surface in Malta[8].

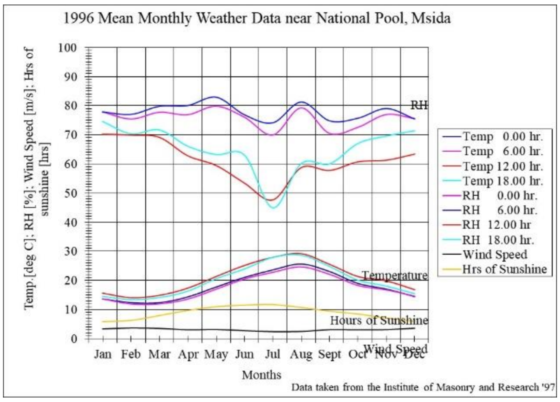


Figure 7: Air temperatures, RH, and wind speed for Malta [8].

It is also interesting to note that the indoor conditions could have been kept within the comfort zone for those moderate months, when the outside air is relatively much lower than the set room temperature of 23.5 °C, simply by increasing the amount of filtered fresh air through an adiabatic controller of the psychrometric process, thus eliminating the need to operate on active cooling. However, this would have required a different HVAC design configuration to cater for such flexibility. For example, the use of a number of semi-industrial air to air unitary units with ducting and grilles for even air distribution or a central heat pump/chiller coupled to one or more air handling units could have offered one solution.

This mixed-mode type of design and operation would not only reduce energy consumption due to free cooling but would have also served as a:

a) Better containment of refrigerant (which can be harmful to the ozone depletion and global warming). Due to the long distribution refrigeration pipework running throughout the building. It is not easy to detect leakages in a timely manner.

b) Less operational noise because there are no indoor units motors as all noise is within the contained air handling unit situated outside or in plantrooms and can be controlled through sound attenuators.

c) Better coefficient of performance since the COP and EER of small bore refrigeration pipework direct expansion VRF units as given by manufactures, do not take into consideration the energy consumed by the indoor units and the substantial pressure drop in the long distributing pipework to serve the indoor units, which could be substantial and depends heavily on the installation..

Finally for this case study one has also to note that in view that the Fan Specific Power (FSP) is given by:

$$FSP = \frac{(absorbed\ \ Power\ of\ supply\ + Return\ Fans)}{\max\ airflow\ of\ either\ Fan}$$

and in this project no return fans were installed, the calculated FSP was somewhat lower and better than the default value of SBEM at 1.5 W/l/s. Thus SBEM gave a better projected yearly energy consumption of 70.09 kWh/m² instead of 72.35kWh/m², when calculated with default values, as was shown in Figure 3.

This is somewhat contradictory and ambiguous because the absence of return fans creates over pressurized internal conditions and consumes more energy, given that a large quantity of treated air, i.e. 10,800 m³/hr gets lost to the external through exfiltration when doors are opened.

This will not only affect the comfort within the zones themselves or problems associated with door closures, but it eliminates the option to recover the energy from the treated air, as an energy saving opportunity.

3 CLUSTER TYPE 3 PERFORMANCE GAP

3.1 The Building Envelope

The Mater Dei Hospital is a 1,000-bed general and teaching hospital, which was completed and commissioned in July 2007. It is unique for Malta, being so large and the sole general hospital on the island cut from mainland Europe or Africa. Its design philosophy had to be similar to an "aircraft carrier in open seas" that is, whatever happens, it has to go to the nearest port on its own steam. In such case it had to be smart thus having:

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) Cultural meeting client expectations.
h) Effective, innovative technology.
i) Construction and management processes.
j) Health and sanitation.

To achieve all this, it went on a Design and Build process included:

- An international integrated design team design to UK NHS standards
- Optimised energy efficient brief
- Optimised plant selection
- Practical use of building management (BMS) controls.
- Intricate handover.
- Computerised maintenance and management systems (CMMS)

Figure 8 shows an aerial overview of the hospital.

Figure 8: Aerial view of Mater Dei Hospital, Msida

The hospital complex is compposed of ten levels from level 6 to level 15 with level 10 as the primary ground floor covering an area of nearly 250,000 m^2.

In 2015/16 a new block Medical Assessment Unit was added inside the open space next to the Emergency Department with all services fed from the same existing plantrooms, while an independent new block (except for the main 11 kV power supply) 108-bed Oncology Centre was built on the east side facing the main entrance (see Figure 9). This is interconnected to the MDH through a high-level bridge, ring road and underground tunnels.

Figure 9: The new Oncology Centre at level 10 with an interconnecting bridge to MDH

The hospital was built on a local village concept inspired by Maltese architecture having its place of worship as its central pointt surrounded by distinct departmental blocks and interconnected horizontally at ground through long circulation corridors for more easy access, with 52No large passenger or bed lifts for vertical movements. These corridors also serve as a quick emergency means of escape through a horizontal progressive evacuation in case of fire. The hospital is unique on the island and in case of calamity it had to withstand until assistance is provided from abroad.

Though at the time of design and build the local Technical Document F [13] was not yet in place as part of the 2012 legislation [2], the architects and designers saw it fit to build with passive design principles and incorporate sustainable conservative environment concepts and materials. All windows are small, fitted with movable blinds inside sealed double pane clear glass and controlled from the rooms and thus remain always clean.They are retreated back from the facade and inclined to make use of natural lighting yet at the same time reduce thermal loading due to the shadows cast by the lintels overhangs for a substantial number of months, thus creating shading.

Its built on a superstructure concrete concept with flat floors and ceilings on columns and beams with light double 20mm thick gypsum partitioning ith 100mm rockwool insulation in between. . The outside walls are in double layer traditional natural light coloured limestone composite wall made up from external face inwards of:

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

Thus having its overall coefficient of heat transmission (U Value) of not more than 0.57 W/m² K.

Uniquely, the use of metal ties in double skin masonry walls eliminated the use of masonry bond stones to tie both skins and function as a double wall, without loss of heat transfer across the bond headers. Moreover, the lack of any physical barriers within the masonry wall cavity allows the introduction of an insulation layer tied with appropriate plastic stays to the inner dry skin and allows an interrupted air cavity between outer skin and the insulation layer within the cavity as shown in Figure 10 below. In view that for such large projects the U values are of high importance this gave a better chance for quality control of workmanship and for the insulation not to detoriate with time.

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 has to be determined. Each predalles section may be considered as solid concrete in three portions, i.e. the edges and the central one, with a 250 mm thick high-density polystyrene insulation sandwich in the other two parts. For floors and ceilings, this gives an overall U value 0.279 W/m^2 K, while for the roof an additional 60 mm thick high-density insulation slab was inserted on top and below the screed to sustain the same U value.

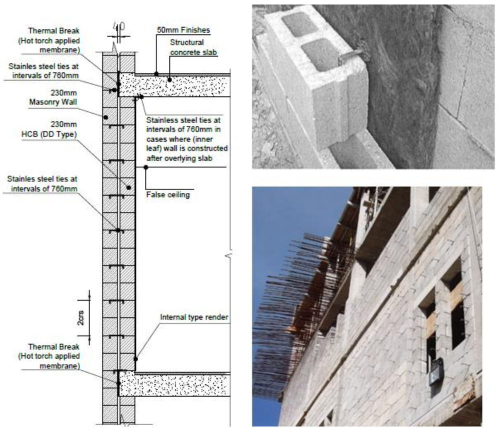


Figure 10: Details of double external walls with metal ties instead of bond stones

3.2 The Engineering System

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 [14]–[17], [18].

- HVAC & DHW Systems

With a closed window policy, the HVAC system of this hospital is a complex constant volume, all year round single pass throw-away type air-conditioning having primary air handling units to treat the required quantity of air for sanitary, as well as taking any latent heat load to absorb the air laden moisture. While a secondary hydronic system takes care of 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 is considered extremely harmful such as in wards and treatment rooms, active type chilled beams are used where the cooling medium is water at a temperature above the dew point of the air. Thus no condensation is possible. Though chilled beams are of the active type they have no fans or motors and sucks return air just by venturi applying Bernoulli's principle. This makes them not only economic but also very silent.

Around 65% of the energy inside the treated fresh air is partly recovered through heat exchangers inside the AHUs between the supply and extract. In areas where the risk of contamination could be hazardous such as wards, treatment rooms run-around (closed loop) coils are used, while in other less risky spaces such as offices thermal wheels are installed being more efficient.

The lighting engineering design was based on CIBSE LG2 – Lighting guide for hospital and healthcare buildings [17], [18] and the appropriate NHS documentation [19]. At the time of lighting design that is in the early 2000s, T5 and light emitting diodes (LEDs) had not entered the lighting market as a cost-effective energy efficient alternative to traditional light sources such as incandescent and T8 fluorescent bulb, so only compact fluorescent lights and T8 neon tubes were used.

- Controls

HVAC plant, fire dampers, staircase pressurization fans, electrical load shedding during power outages, various alarms from systems such as medical gas, lifts, tanks, air craft warning lights and the laundry chute system and others, are connected to a 60,000 point BMS that controls, monitors and supervises through 73 panels with a ring network and graphics and human-machine interfaces. The BMS comprises of:

- 970 temperature sensors
- 920 pressure sensors and switches
- 99 humidity sensors
- 605 control valves
- 435 air damper actuators
- 100 motor starters, 210 of which are VSDs

3.3 SBEM Rating Results

In 2015 a contract was given to a local firm having a team of registered assessors on non-dwellings to issue an Energy Performance Certificate in line with the local legal notice and BRO methodology using SBEM-mt 4.2c software.

The certificate was based on a sample of the whole building at level 10 (Ground Floor) of Block D1, which is primarily composed of medical wards next to the emergency department. This was reported as having an annual Primary Energy Consumption of 1,375 kWh/m².yr and a CO_2 emission of 351 kg/m^2.yr, as shown in Figure 11.

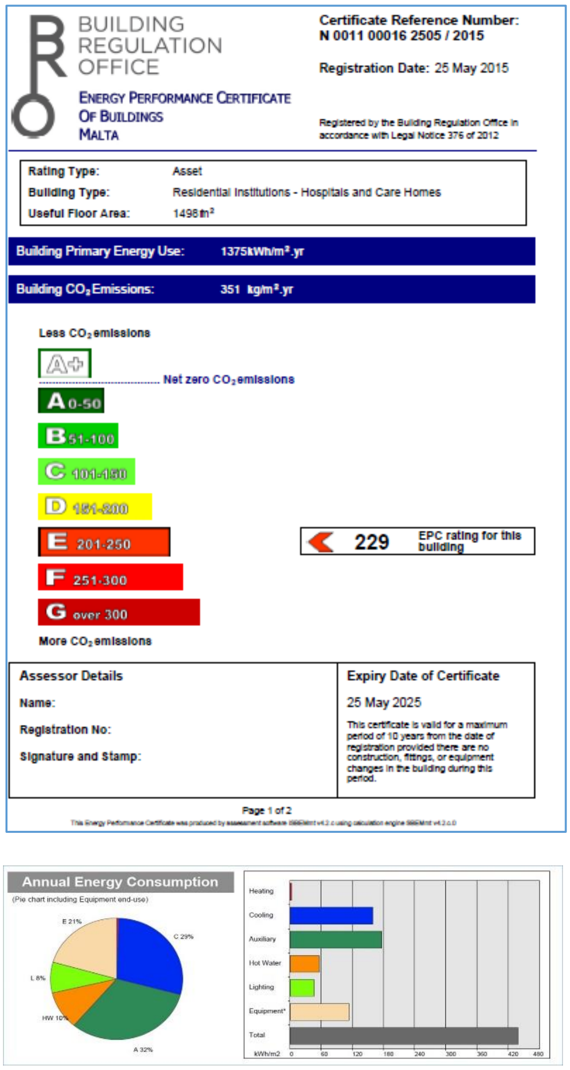
3.4 Actual Measured Energy Consumption

Monthly electricity bills were used to calculate the exact electrical energy and fuel consumed during the years 2014 to 2016, as shown in Table 5. Electricity alone is nearly one million kWh per week.

Table 5: Fuel and electricity consumption at MDH during 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

One has to note that while during the years 2014, 2015 the New Oncology Centre and the Medical Assessment Unit were being built and power was taken from the MDH electrical substation to construct them, in 2016 these were commissioned and handed over and therefore the floor areas increased by 10%.



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 m²

Building Primary Energy Use: 1375kWh/m².yr

Building CO_2 Emissions: 351 kg/m².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
F 251-300
G over 300
More CO_2 emissions

229 EPC rating for this building

Assessor Details
Name:
Registration No:
Signature and Stamp:

Expiry Date of Certificate
25 May 2025
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.

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 11: MDH Energy Performance Certificate.

In order to compare the actual energy consumption to the SBEM EPC results, the year 2015 is chosen. The same primary energy conversion factor as that of SBEM-mt software (3.45), will be used to convert the actual electricity consumption to equivalent primary energy. This results in primary energy of 220,456,846 kWh/year.

Similarly, if one multiplies the gasoil consumed by its density and calorific value plus 10% extra for transportation, the primary energy would become 18 million kWh, as shown in Table 6.

Table 6: Primary Energy for type D gasoil fuel

Year	2015	units
Fuel type	gasoil	
Consumption	1,536,900	litres
Density	850	kg/m^3
Weight of fuel	1,306,365	kg
Gross Calorific value	45.5	MJ/kg
Total energy consumed per year	59,439,607,500	kJ
Fuels consumed	16,511,002	kWh
Grid factor	1.1	
Primary Energy Consumed	**18,162,102**	**kWh**

Therefore, the total primary energy of the hospital as actually consumed in the year 2015 amounts to 956 kWh/m^2 yr.

The equivalent carbon emission rating, using the SBEM-mt conversion ratio of 0.878, amounts to 187 kg/m² yr.

These figures are much lower than those reported in the SBEM-mt outputs of 1,375 kWh/m² yr and 356 kg/m².yr, respectively.

The actual energy consumption for the three consecutive years 2014-2016 are shown in Table 7. Despite the fact that the hospital has been enlarge in 2016, , the overall energy emissions and carbon rating are still lower than SBEM results.

Table 7: Comparison between SBEM and actual primary energy used.

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 Primart Energy Used	199,557,367	238,618,948	279,253,646	kWh
Unit Actual Primary Energy Used	800	956	1,017	kWh/m^2
SBEM				
Unit CO_2 produced due to primary electricity	145	167	177	kg/m^2
Unit CO_2 produced due to primary fuel	15	20	21	kg/m^2
Total CO_2 produced per unit area (EPC certificate)	**160**	**187**	**198**	kg/m^2
Percentage rise from 2014		17%	24%	
mean		**182**		kg/m^2
standard deviation	min	**166**		kg/m^2
	max	**198**		kg/m^2

This difference is substantial notwithstanding that the readings taken included all the energy used for an entire operating hospital with 24 Theatres, ITU, CSSD, the Faculty of Health Sciences, administration, staff canteen, X-ray and other machines. These loads are not included in the SBEM-mt EPC results, in accordance with the EPBD methodology. Therefore, for this case, SBEM-mt EPC results are over-estimated by 38%.

3.5 Discussion

This energy performance gap needs to be identified and studied even further. One of the best ways to analyse these results further is to study the sectorial energy consumption. The BMS as designed is not exactly similar to the output of SBEM-mt. However, with some analytical work the long list of equipment installed was split into various systems such as cooling, heating, domestic hot water, ventilation. The relevant quantity of installed equipment was multiplied by the absorbed current (taken as 80% of its nominal nameplate value) and the number of hours in operation to obtain a reasonably conservative estimation of the annual energy used.

3.5.1 Cooling energy consumption

Mainly, this load consists of the energy absorbed by the 16No packaged water chillers. In view, those chillers are not directly metered and the best way to calculate their consumption is by going through the compressor running hours and multiply this by the nominal current for each system.

Detailed analysis for 122 months from the first day of commissioning up to date, an average annual energy consumption of 20,283 million kWh with a yearly unit loading of 81,27 kWh/m^2. This contrasted heavily with the 158 kWh/m^2 given by SBEM for overrating the certificate by 48.56%.

Another method was used to confirm that the above calculation is reasonably accurate. The chilled water production energy readings of the BMS for the last two years were analysed. Every 15 minutes the BMS gives readouts of the chilled water produced by each chiller taking into account the primary chilled water flow and water temperature entering and leaving at each chiller. The readings for the last two years were compiled and manipulated such that every four readings were averaged to give the hourly kWh. When all the months were added up and divided by 24, gave a yearly average of 38,574 million kWh. This was divided by the seasonal coefficient of performance (SCOP), which was found to be 1.77 gave an annual energy consumption of 19,287 million kWh. This is very similar to the 20,283 million kWh that was calculated previously using the compressors running hours.

3.5.2 Heating energy consumption.

The heating energy usage is mainly associated with the energy used by the hot water boilers, which operates on gasoil. In view that these boilers provide hot water for both space heating, as well as for the provision of domestic hot water (DHWS), the quantity of fuel used was assumed to be split equally between them. This worked out to give an annual energy usage of 8.255 million kWh with a unit loading of 33.08 kWh/m^2, which contrasts heavily with 4 kWh/m² given by SBEM. This underrated this part of the certificate by more than 700%.

3.5.3 Auxiliaries

As for the auxiliary energy usage, the installed equipment was divided into various sections for the production of chilled water, hot water and ventilation, which gave an annual energy usage of 5.968, 3.831, and 12.526 million kWh per year, respectively. This translates to 63.056 kWh/m^2.yr against the 176 kWh/m^2.yr, as predicted by SBEM. This amounted to an overrating of around 64%.

3.5.3 Domestic Hot water

The energy associated with the remaining half 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 usage of 8.389 million kWh, which translates to 33.61 kWh/m².yr. At 44 kWh/m².yr this was underrated by SBEM by around 24%.

Another assessment was made to try and reconcile the actual hot water demand to that estimated by SBEM. This is because the first attempt of dividing the fuel consumption equally between space heating and hot water production resulted in an over-estimation of space heating and an under-estimation for water heating. A fuel consumption share of 35% space heating to 65% hot water was therefore used. This gave an overall overrating certificate of around 38%. The performance on a system by system is shown in Table 8 below.

Table 8: Overall performance for SBEM as compared to the actual energy usage of MDH.

System	**Average kWh/m^2 yr.**		**Percentage Rating by SBEM as compared to actual**
	SBEM	**Measured & Actual**	
Heating	**4**	**22.68**	**-466.99% under rating**
Cooling	**158**	**81.27**	**48.56% over rating**
Auxiliary	**176**	**89.46**	**49.17% over rating**
Hot water	**44**	**44.01**	**-0.02% over rating**
Lighting	**57**	**42.47**	**25.49% over rating**
Total	**439**	**279.89**	**36.24% over rating**

3.5.4 Lighting

In order to determine the actual annual energy used by lighting each of the 30,080 installed luminaires were identified on a block by block level, its installed power recorded and multiplied by the hours of operation as per individual time schedules. This practically covers all lamps within the hospital except for the street and surface lighting, which after all are even included in the energy consumption and calculated within the electricity bills of the hospital. The unit annual lighting load amounted to 42 kWh/m².yr, as compared to the 57 kWh/m².yr given by SBEM. This amounted to an overrating of around 25%.

3.6 Assessing Energy Performance of Cluster Type 3

Figure 12 shows the summary results of actual and simulated primary energy outputs. Cooling is the main sector that consumes most energy, together with the auxiliaries mainly connected to the services.

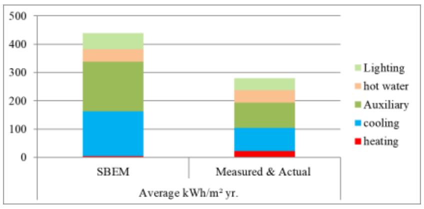


Figure 12: MDH Energy performance as predicted by SBEM and actual on-site energy consumption.

4 REFLECTIONS AND POSSIBLE SOLUTIONS

Overall, when one compares the energy performance of both clusters as given by SBEM to that as actually measured on site, it is found that they heavily swing in the predicted energy usage, from an underrating of around 64% for cluster type 2 buildings such as offices, to an overrating of about 36% for more complex cluster type 3 buildings such as Mater Dei Hospital, as shown in Figure 13.

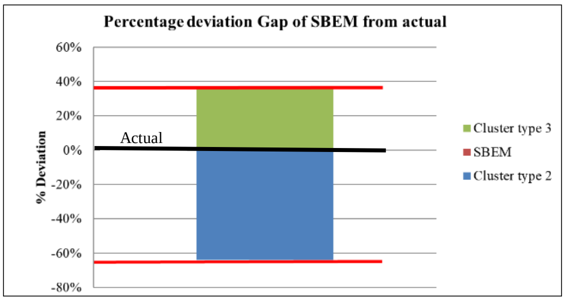


Figure 13: Graphical representation of the performance gap for different types of buildings

So, there is a mismatch between the expectations around the performance of new 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 the other countries including the UK. But in UK the difference is always on one side with buildings using more energy than that predicted, as shown in Figure 14.

One has to take into account that SBEM as is amply explained in its technical and operating manuals is primarily an Asset Rating methodology that can be performed on buildings that are in design or completed habitat stages. It is more to check if a building has been built to some type of standard such as in UKL Part L2.

As such in UK they use a different methodology to calculate the energy performance for such non-dwelling buildings. This is known as the Display Energy Certificate (DEC), which is required for buildings occupied by public authorities and by institutions providing public services to a large number of persons. The (DEC) is based on actual on site energy consumption similar to the old CUSUM method. This is a certificate that incorporates a numerical indicator of performance, known as the Operational Rating (OR), which is the ratio of total actual measured energy use of the building over a year to a benchmark for a building of same type and given a grade from A to G based on measured carbon emissions. Such methodology and ratings are given in TM47 Operational Ratings and Display Energy Certificate [21]. Figure 15 shows an example of the OR certificate.

In the OR there are 29 benchmark categories, each representing a major functional group of buildings, so that they can provide an indication of how a building is performing in relation to a wider group. The categories and classifications are kept under constant review for statistical data with on-going research papers [7 ~17], to substantiate this procedure as being fit for purpose and reap its contribution to more sustainable energy approaches.

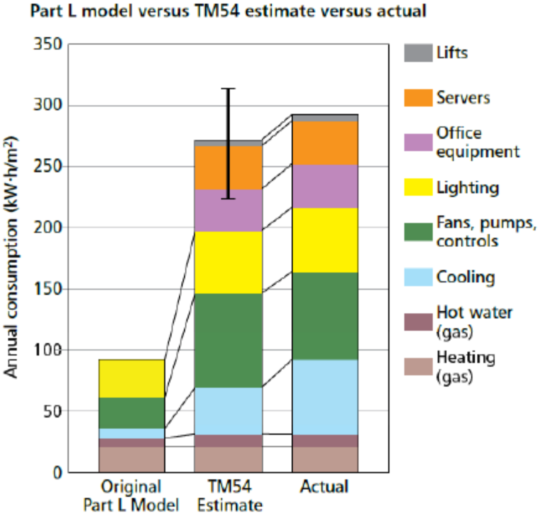


Figure 14: Comparison of compliance, design modelling and actual energy use

In a preliminary research overview, it was seen that a number of researchers are working on the performance gap issue. In his paper, Wilde [14] has identified a number of strategies that can be explored to study and come up with a calibration methodology to bridge this gap. Menezes et. al. [15] 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 within 3% of its actual consumption. This will be studied in greater detail for Malta's case.

In his paper, Choudhary [16] has identified certain factors that could play an important role in determining the extent of gap between predicted and actual energy performance of buildings, which includes the area, the use of the building and even the fact whether the building is situated in a city or the outskirts. His findings will be further studied and adapted for use in Malta's case. Heoa [17] looked at the problem from a different angle, whereby he incorporated sources of uncertainties in his study, such as physical properties and equipment performance. However, he highlighted the fact that other dynamic uncertainties need to be taken into account, such as the aging of equipment over time. All these studies and much more will be studied in greater detail before proposing the best methodology to be implemented in this PhD study.

The final product would produce sufficient knowledge that will primarily answer the following questions:

1. What is the optimum methodology to achieve energy efficiency in non-residential buildings?
2. Which models are adaptable to rate the energy performance of the different types of Maltese non-dwellings?
3. What criteria should typically be applied to achieve a minimum level of energy efficiency in buildings?

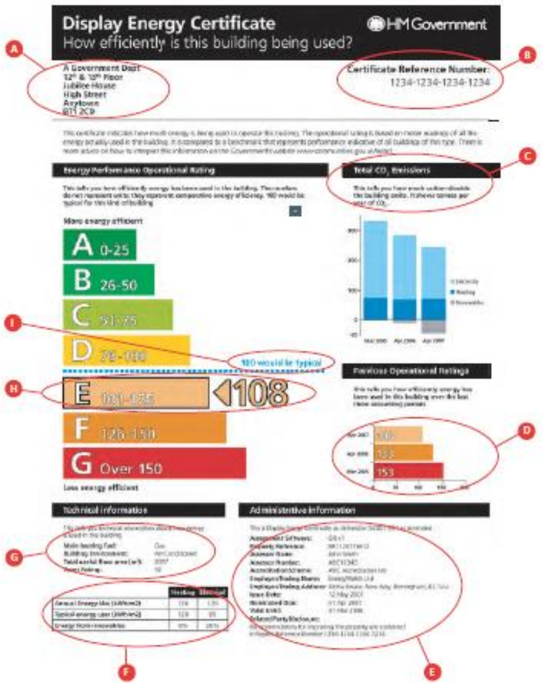


Figure 15: Example of a Display Energy Certificate (DEC)

5 CONCLUSIONS

This paper has proposed a clustering of non-residential buildings, in order to compare their actual energy consumption to their energy performance certificate outcomes.

Cluster Type 1 includes elementary non-residential buildings, which are nearly free-running buildings or are very similar in the fabric to domestic premises and services present, such as schools or a block of shops with say flats or apartments above them.

Cluster Type 2: non-residential buildings, where comfort conditions need to be controlled utilizing “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 plus artificial lighting. Offices and restaurants fall under this cluster type definition.

Cluster Type 3: are 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, and other extensive amenities.

The paper presented results of two buildings representing Clusters Type 2 and 3, namely a large office building and a general hospital.

Results have shown that SBEM-mt software results are under-rated for Cluster Type 2 building and are over-rated for Cluster Type 3 building. Furthermore, it was shown that this discrepancy is primarily concentrated in the calculation of space heating and cooling for both cases.

A number of proposed solutions as being presented by other scholars have been presented. Future studies as may be applied to Malta within the ongoing Ph.D. study will provide further insight in the near future.

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