EPBD cost-optimal analysis for non-residential buildings in Malta

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Abstract: The Energy Performance of Buildings Directive (EPBD) 2010/31/EU requires EU Member States to calculate the cost-optimal levels of minimum energy performance requirements for new buildings and buildings that undergo major renovation. The European Commission Delegated Regulation (EU) No 244/2012 and accompanying Guidelines 2012/C 115/01 establish a comparative methodology with regards to number of reference buildings for each building category, number of energy efficiency measures to be implemented in the study and the minimum level of cost analysis that is required. This paper fulfils the above requirements but also introduces an innovative approach that goes beyond the minimum requirements for the cost-optimal study, whereby a two-stage optimisation approach was undertaken. The first stage focuses on choosing a representative set of combined building envelope measures that cover the full range of possible energy performance levels, in such a way that these lie along the line of minimum space conditioning costs, known as the Pareto Front. While the second stage applies combinations of energy systems' upgrades to the selected iterations of stage 1. The scope is to minimize the time cost of these cost-optimal studies without sacrificing on their effectiveness or creating biased results. Cost optimal and nearly-zero energy levels were found for homes for the elderly, hotels, offices, restaurants, shops and sports complexes. Results showed that cost optimal levels are best achieved through upgrades of energy systems and solar shading rather than building envelope U-value upgrades for all building categories. This is primarily a result of the mild Mediterranean climate of Malta. Solar water heating and solar photovoltaics have shown to be cost optimal for all categories, except where these cannot be installed such as in shops and restaurants. Shading, heat pump water heaters and high efficiency air-conditioning systems have also been identified as cost-optimal measures.

1. Introduction

The Energy Performance of Buildings Directive (EPBD) 2010/31/EU and its associated regulation [1, 2] have provided clear guidelines on how cost optimal primary energy performance levels are to be calculated for different categories of buildings. The main scope is to gradually push the minimum energy performance requirements towards the nearly-zero energy levels, as costs for energy efficiency upgrades drop by time. The revised EPBD (2018/844/EU), which amends parts of the 2010 EPBD and introduces new elements, has emphasized on the need to continue the cost-optimal approach in a consistent and iterative manner, with more focus being stressed on building renovations [3].

The term "cost-optimal" refers to the state of achieving the least global (life cycle) costs for a set or multiple sets of combined energy efficiency and renewable energy measures (termed package of measures) that can be applied to a particular category of buildings. This should not be confused with what investors consider as an attractive investment opportunity. This scenario requires the investor to achieve a positive net present value (NPV) over a specified calculation period when implementing a chosen package of measures. In contrast, the calculation of the cost optimal energy performance level and application of the corresponding (cost-optimal) package of measures for a particular category of building, results in the lowest global life cycle costs (20 years non-residential; 30 years for residential) but does not necessarily result in a positive net present value or an attractive payback period to the private investor.

Due to different climatic regions and various building technologies, the EPBD requires every Member State to calculate the cost-optimal levels of minimum energy performance requirements (Art. 5 EPBD). A cost-optimal approach guarantees a holistic approach to the implementation of energy efficiency and renewable energy measures, which will lead to improved building energy performance at least global cost, to improved energy security and to lower carbon emissions, thus contributing towards the EU's overall target for carbon neutrality by 2050.

The term "global cost" used in the cost optimal level calculations is the total combination of costs, such as capital cost, maintenance and replacement costs, as well as operational costs, all discounted to the present value over a period of 20 years (for non-residential buildings) or of 30 years (for residential buildings), as stipulated in commission delegated regulation No 244/2012 supplementing the 2010 EPBD [2].

Several sensitivity analyses to the cost-optimal methodology calculation for a reference building under study are also carried out using different combinations of energy efficiency measures, renewable energy and carbon emission costs. For the cases where carbon emission costs are taken into consideration, and when taxes and subsidies are omitted in the cost-optimal methodology, the term "macro-economic" analysis is applied [2].

For the purpose of determining the cost optimal levels for non-residential buildings in Malta, the macro-economic analysis with 3% discount rate is taken as the accepted scenario for the different energy efficiency measures, while the macro-economic analysis with 3% discount rate and with renewable energy systems installed on site is being proposed for the nearly-zero energy performance levels.

2. Literature Review

The main aim for determining cost optimal levels is to check whether the energy efficiency measures employed to attain those levels are reflected in the minimum energy performance requirements, known as Technical Document F (for the case of Malta) [4, 5]. In the event that the difference between the primary energy rating of the building – assuming it to be constructed according to the present minimum energy requirements of Technical Document F standards – is higher than 15% from that determined for the cost optimal levels, then a significant discrepancy between the outcome of the cost optimal cost calculation and the minimum requirements currently in force exists [2], and Technical Document F will have to be updated to stipulate minimum requirements for the building envelope and systems that lead to cost optimal energy performance levels.

Another aim of these studies is to determine to what extent, the different building categories can achieve nearly-zero energy levels, which will have to be adopted by 1st January 2021, across the EU. As mentioned above, the difference between the cost-optimal and nearly-zero energy levels can be calculated via the consideration and integration of renewable energy systems installed on site or nearby in the design of buildings, when defining nearly-zero energy performance levels .

Therefore, the rationale of the EPBD is to first attain energy efficiency levels that are cost-optimal to reduce energy demand and then apply renewable energy systems to further reduce carbon emissions and achieve nearly-zero energy status [6]. Ferreira et al claim that once the cost optimal energy performance is reached, it is often more cost-effective to use renewable energy sources than to aim for decreasing energy demand [7].

The new upgrade to the EPBD (EU) 2018/844 further elaborates on improving the energy performance of the building stock, with focus on building energy renovation. Moreover, it introduces new aspects that will need to be considered in new and renovated buildings such as the necessity to include carbon emission, consider indoor comfort and air quality as part of the energy performance certificate (EPC). Moreover, it proposes two additional measures, which are the smart-readiness indicator (optional) in EPCs and the requirement to include a mandatory minimum number of electric car charging points within new and renovated buildings.

2.1 Current minimum energy performance regulations in Malta

The current minimum energy requirements as published in Technical Document F specifically addresses a two-tier compliance approach, whereby buildings will have to firstly achieve not more than the stipulated overall building primary energy rating, as calculated by the official national calculation methodology for that category of buildings. Table 1 shows the prevailing set limits. Secondly, the building must abide by specific limits set for the elemental components forming the building envelope, as well as minimum compliance for energy efficiency set for space heating and cooling, water heating and lighting installations [4, 5]. Table 2 below shows the maximum transmissivity values for different elemental fabric material. The U-value of 1.57 W/m^2K for external walls reflects the traditional way of building façade cavity walls composed of two globigerina limestone skins and separated by an air gap and 10% bond stone. It is to be noted that this U-value applies to all external walls except for those abutting bathrooms, utility rooms or sanitary conveniences that have less than 5.6 m^2 of area. Such rooms usually overlook internal shafts or small yards. The U-value for roofs of dwellings is different from that of offices. In practice, a typical in-situ concrete roof would require at least 0.05 m of insulation material to achieve 0.59 W/m^2K and 0.075 m of insulation to achieve the more stringent level of 0.4 W/m^2K. Non-exposed floors are floors that are abutting unconditioned spaces such as underlying garages.

Table 1: Overall maximum allowable primary energy rating for different non-residential building topologies as reported in Technical Document F (2015) – Part 1 [4].

Building topology	Maximum overall primary energy rating (kWh/m^2. year)
Offices	290
Buildings with >50% occupied by offices	350

Table 2: Maximum transmissivity values (U-values) for elemental building fabrics of Technical Document F [4]

Building element	Maximum U-value (W/m²K)
Exposed wall	1.57
Exposed Floor	1.57
Non-exposed floor	1.97
Roof - dwelling	0.59
Roof – non-dwelling	0.4
Exposed walls of bathrooms, sanitary conveniences and utility rooms having an area of 5.6 m² or less are excluded from this requirement. Exposed building elements of washrooms, storage rooms, plant rooms, garages, or other spaces with no space conditioning system and not internally connected to the main conditioned space are excluded from this requirement.	

Table 3 shows the maximum allowable areas for glazing elements for different orientations, while Table 4 shows the prevailing U-value limitations for windows and roof lights and their maximum aggregate percentage areas.

Table 3: Maximum allowable glazed areas for different orientations.

Orientation of opening	Maximum allowable unprotected area of the opening (%) Assuming 0.2 frame factor
N	25
S	20
NE	17
E/SE/SW/NW	12
W	9
Horizontal (roof lights)	7
The maximum allowable area of glazing for windows with an orientation falling in between the compass directions should be taken as the highest allowable area for the two directions.	

Table 4: Maximum overall glazing U-value and the corresponding maximum aggregate glazed surface area.

Building type	Windows and skylights maximum U-values (W/m²K)	Aggregate area as % of the area of the exposed walls bounding the building
		Windows & doors
Offices, places of assembly	4.0	25%
Showrooms, shops	4.0	50%
Windows and doors of bathrooms, sanitary conveniences and utility rooms having an area of 5.6 m² or less are excluded from this requirement.		

2.2 The national energy performance calculation methodology for non-dwellings

In 2011, Malta has adopted the quasi-steady state national software to be used for the issue of energy performance certificates for non-dwellings, known as the Simplified Building Energy Model for Malta (SBEM-mt) [8]. The software is based on the British SBEM but with an added cooling component and customized to use Malta's climatic weather conditions for the year 2010. Trained assessors are registered to issue energy performance certificates, based on the specific inputs pertaining to each building.

3. Methodology

The methodology was divided into four stages. First, it was necessary to identify reference buildings that can represent the different building categories. Twenty-eight buildings were chosen to represent the topologies of non-residential buildings as follows:

- Offices: 3 detached (cellular and open plan) and 3 terraced (cellular and open plan).
- Hotels: Three and four-star hotels forming the major categories of hotels in Malta.
- Restaurants: Detached restaurants and restaurants within existing multi-use buildings, also including street level glazed enclosures.
- Retail shops: Small family-run shops, shops within a shopping mall, a supermarket (with chilled areas) and a showroom (with no chilled areas).
- Homes for the elderly: public and private buildings.
- Schools: Small church school, larger public and private schools.
- Sport complexes: Small and large.

Table 5 shows the inbuilt primary energy conversion factors that are used for the current version 4.2c of the software SBEM-mt [6].

Table 5: Inbuilt primary energy conversion factors in SBEM-mt v4.2c software.

Fuel source	Primary energy conversion factor
LPG (propane or butane)	1.10
Heating Oil	1.10
Diesel	1.10
Kerosene	1.10
Biodiesel	1.20
Grid Supplied Electricity	3.45
On-site Generated Electricity	3.45

The second stage of the study calculated the primary energy rating for the reference buildings without and with different set of packages of measures, as required by the EPBD. The choice of package of measures was carried out diligently. They included the variation of thermal insulation for walls and roofs, shading and spectrally selective glass coatings, high efficiency air-conditioning systems, heat pump and solar water heaters and rooftop solar photovoltaic systems. It was concluded that other measures do not apply for the case of Malta and were therefore not considered at this stage. These may be summarised as follows:

- Extremely low U-values for the building envelope and glazing, because of Malta's temperate climate and because they may lead to higher cooling loads, which offsets their benefits for the short winter season of Malta;
- Air to air Heat recovery due to Malta's mild climate and high humidity levels;
- Solar cooling as it is generally still not cost effective as explained in the actual cost-optimal reports;
- Solar photovoltaics on façade, due to the high concentration of buildings that overshadow one another, thus causing low energy generation for the solar photovoltaic vertical façade systems;
- Geothermal and combined heat and power with cooling systems, hybrid solar fibre optics and sun pipe lighting and Stirling engine for electricity generation, were all identified as being expensive for the time being to justify their widespread use.

The third stage carried out an optimisation exercise for the building envelopes by adopting the method proposed by Hamdy, Hasan, and Siren [9]. The advantage of taking this approach is to minimize the number of iterations, without compromising the outcome of the cost optimal study. The building envelope iterations will affect the heating and cooling demand for the building. Therefore, the heating and cooling demand of each package of building envelope measures was plotted against the Present Worth (PW) of each measure, as shown for one example in Figure 1. The PW is the initial and replacement costs of the addressed measures.

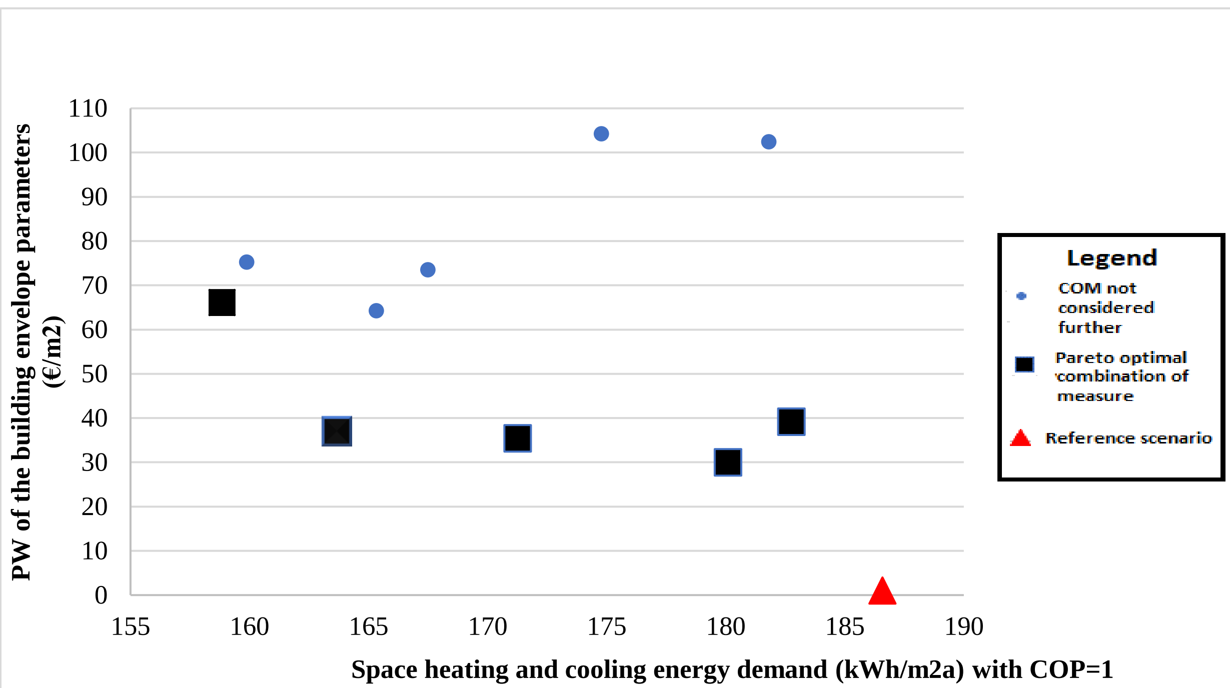

Figure 1: Plot of Present Worth (PW) of each combination of measures in Euro/m^2 of floor area against space heating and cooling demand (kWh/m^2 per year, for one home for the elderly)

From the graph of Present Worth (PW) in Euro/m² of floor area against space heating and cooling demand (kWh/m²a), five (5) Pareto optimal combination of measures (COM1 to COM5) were chosen, as highlighted in black dots. These points must cover the full range of possibilities from the cheaper to the more expensive PW, along the Pareto Front. When comparing these points to other points in the graph, for the same heating and cooling loads, the points lying at the Pareto Front will offer the cheapest PW for that level.

The fourth and final stage involved the calculation of the primary energy rating and the corresponding global costs pertaining to each and every combination of measures (the five optimised pareto front envelope scenarios combined with energy systems improvements – space heating and cooling, heat pump water heating, solar water heating and solar photovoltaics). For each category of building, there were between 72 and 144 different iterations, which is much higher than the requested EPBD minimum iterations of 10 plus the reference case [2]. Figure 2 below summarizes the whole methodology approach.

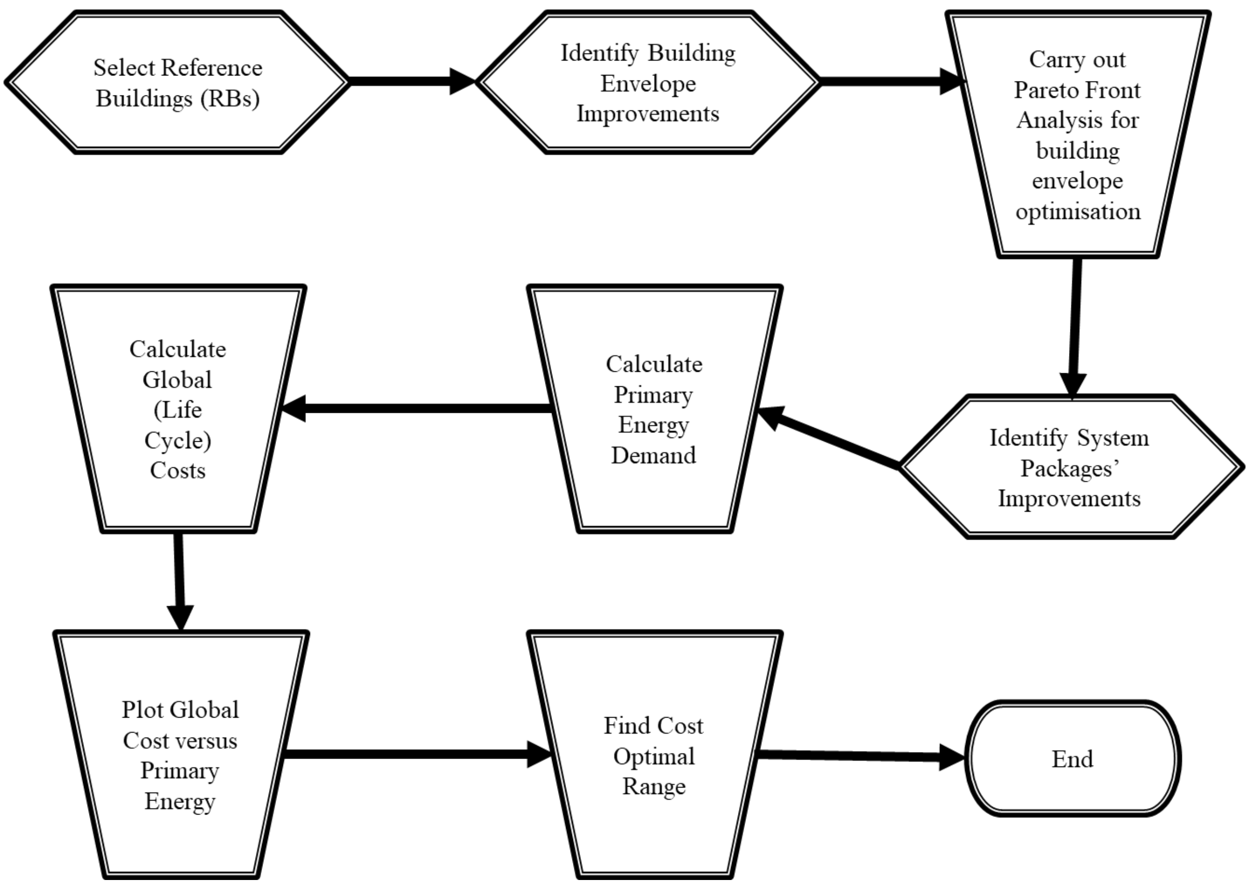

Figure 2: Outline of the methodology approach used to determine the cost optimal levels of non-residential buildings in Malta.

4. Results

As mentioned earlier, the cost optimal levels were determined using the macro-economic analysis with 3% discount rate without the consideration of solar renewable energy, while the levels being proposed for nearly-zero energy performance, were determined for the same macro-economic analysis with 3% discount rate and including solar renewables. The outcome results are shown in Table 6. It is to be noted that whereas more than one reference building has been considered for each category of buildings, the cost optimal levels and the proposed nearly-zero energy levels were taken for the worst performing building in that category, in order to ensure that all buildings within that category will be able to achieve the proposed cost optimal levels and the proposed nearly-zero energy levels.

The results of the cost optimal study have also shown that there are common elemental solutions that apply to all buildings. On the other hand, some additional cost optimal measures apply to specific building categories. Moreover, the application of a minimum introductory amount of solar renewable energy has been identified as a feasible elemental measure (from an EPBD cost-optimal perspective) that can be introduced in new buildings, as shown in Table 7. However, restaurants and small shops forming part of a larger building have been excluded from the requirement to install solar photovoltaics given that they generally do not have access to roof space.

Table 6: Cost optimal and proposed nearly-zero energy levels for non-residential buildings.

Building	**Cost optimal range and cost-optimal point in brackets (kWh/m². year)**		**Nearly-zero energy levels and nearly-zero energy cost optimal point in brackets (kWh/m². year)**
	New	Renovated	New
Homes for the elderly	731 – 778 (736)	735 – 898 (747)	698 – 749 (703)
Hotels	786 – 841 (786)	901 – 977 (901)	757 – 841 (757)
Restaurants	1534 – 1904 (1534)	1552 – 1960 (1595)	1534 – 1904 (1534)
Schools	318 – 397 (369)	327 – 417 (375)	211 – 285 (233)
Shops	775 – 826 (775)	781 – 908 (887)	556 – 606 (556)
Sports complexes	607 – 632 (618)	715 – 730 (638)	515 – 632 (526)
Offices	456 – 509 (464)	Not available yet	405 – 462 (405)

Table 7: Recommended elemental measures that were shown to be cost-optimal for new and renovated non-residential buildings or adopted from the existing Technical Document F- Part 1.

Common elemental requirements for: • Homes for the elderly • Hotels • Restaurants • Schools • Shops • Sports complexes • Offices	• External wall U-value: 1.57 W/m²K • Semi-exterior wall U-value: 1.97 W/m²K • Roof U-value: 0.4 W/m²K for non-residential building • Bathrooms, sanitary conveniences and utility rooms shall no longer be exempted from the maximum U-value limitations for walls. • Glazing U-value: 4 W/m²K • Keep the previous limitation on glazing percentage areas (Tables 3 and 4), except for restaurants whereby glazing area may be increased provided that shading or spectrally selective coating is applied. • Minimum shading factor of 0.5 under certain criteria. For shops and restaurants, this may be replaced by an equivalent spectrally selective coating that provides the same effect. • Minimum coefficient of performance of 4 for air-conditioners. • LED lighting.
Additional requirements for: • Homes for the elderly • Hotels • Restaurants with total floor area greater than 150 m² • Schools • Sports complexes	Solar heating or heat pump should cover at least 5% of total hot water needs (as calculated by SBEM-mt software) given that the use of renewables to satisfy hot water demand was found to be cost-optimal. This is the minimum level that one would recommend given that no mandatory requirements for including solar systems in new and renovated buildings exist in Malta and given that roof space may be limited due to the particularities of building topologies in Malta.
Additional requirements for: • Homes for the elderly • Hotels • Schools • Shops with own roof • Sports complexes	Renewable electricity should cover at least 5 % of the annual primary energy (as calculated by SBEM-mt software) given that application of roof mounted photovoltaics was found to be cost optimal. This is to be increased to 15% for schools.

An example of a nearly-zero energy level graph is shown in Figure 3. It is to be noted that the reference scenario had a primary energy rating of 1,102 kWh/m². year, which is outside the range of the x-axis scale. The detailed studies have already been published on the EU Energy platform [10].

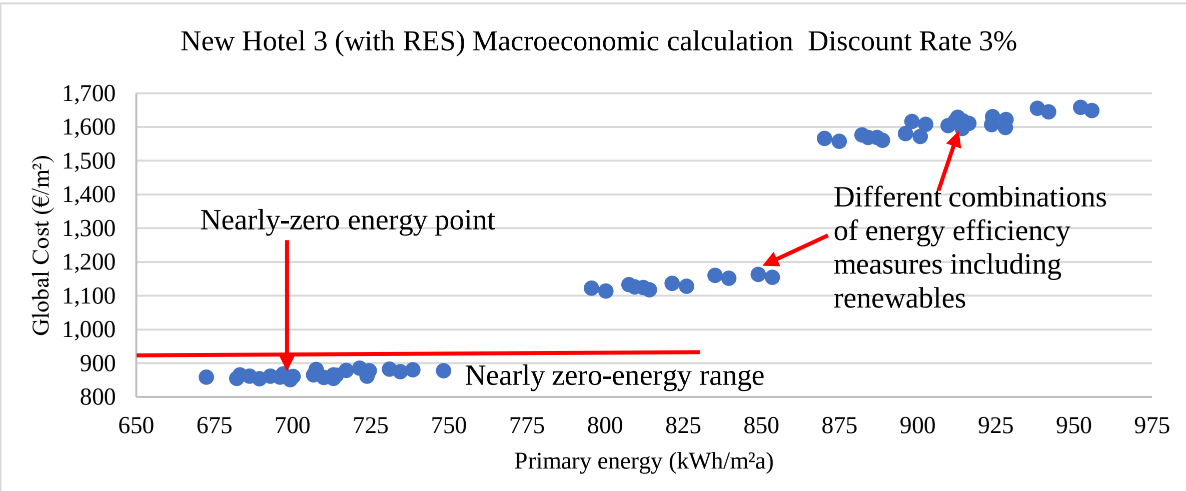

Figure 3: An example of a nearly-zero energy level graph for a reference hotel

5. Discussion

The outcome of the cost optimal studies has shown that for non-residential buildings, the improvement in the insulation properties of opaque elements plays a minor role in the improvement of the energy performance levels. This is a direct effect of the mild Mediterranean climate of Malta, whereby the maximum temperature difference between the external temperature and the set internal temperatures rarely exceeds 10 °C, as opposed to Northern European countries, where temperature difference could reach up to 40°C. In general, costs of insulation and finishing is relatively high in an island scenario where most insulation materials are imported. Concurrently, Malta's electricity tariffs are reported to be the fourth lowest in the EU [11], which further reduces the cost effectiveness of energy efficiency measures for the building envelope. On the other hand, the effect of shading is significant, given the high solar intensity in Malta reaching up to a maximum of 8 kWh/m². day on the horizontal during July. The results for insulation and shading obtained from the cost optimal studies are consistent with the outcomes of local literature studies including [12,13,14] that were carried out using the state of the art dynamic EnergyPlus [15] calculation engine.

The removal of exceptions to wall and glazing U-values of bathrooms, sanitary conveniences and utility rooms, as stipulated in the 2015 Technical Document F is recommended, because the effect of using inferior U-values for those walls or glazing will negatively impact the overall energy rating of the building and the cost optimal levels.

With regards to energy systems, the highest impact can be seen by shifting to heat pump water heaters for building categories that have high hot water demand, such as hotels, restaurants and homes for the elderly. Space heating and cooling using high efficiency heat pump has also systematically appeared in all the cost optimal studies. This is to be expected given that the heating and cooling loads form the bulk of the energy demand of the non-residential building categories under consideration. Some energy efficiency measures, e.g. roof insulation and LED lighting, have been taken by default, because they are already very well accepted by society as cost effective.

Although the nearly-zero energy point has been determined, as shown in the example in Figure 3, it is clear that there are many other combinations of measures (to the left of the nearly-zero energy point) that could yield very close results but lower (better) primary energy ratings. This is advantageous to designers and architects, because it gives them flexibility in their designs in order to achieve the best results. In other words, the cost optimal study does not in any way limit creativity and flexibility in building design. It only sets the minimum energy requirements that guarantees least global cost for the building.

6. Conclusion

The cost optimal studies have been carried out for most types of building categories. The study has shown that there are many combinations of energy efficiency and renewable energy measures that fall within the cost optimal range or near zero energy levels. These results can be used to the advantage of building designers, as it increases their options to achieve the minimum energy performance requirements.

The cost optimal studies have identified key energy consumption sectors, which may impact energy performance significantly. These are primarily space cooling and water heating. Results have also shown that the impact of implementing high efficiency energy systems in non-residential buildings is higher than the upgrading of building envelope elements beyond the current set limit of Technical Document F, except for shading. This is a direct effect of the mild weather climate of Malta, whereby the difference in temperature between external and internal conditions rarely exceeds 10 °C, both for summer and winter. However, this does not mean that inferior U-values can be used, because they would then drastically affect the energy performance of buildings. In other words, the existing set limits of U-values for walls, roofs and floors as depicted in Technical Document F are very well balanced and in line with the cost optimal results. The study has also shown that there is potential for the introduction of renewable energy systems within buildings. These have been proven to be cost optimal for all cases.

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