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# ZEROCO$_2$ BUILDINGS – HOW LOW CAN WE GO: A CASE STUDY OF A SMALL HOTEL IN GOZO

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ABSTRACT: This study has shown that a new typical hotel building in Malta can reduce its CO$_2$ emissions by more than 75 % over a chosen reference scenario with a relatively reasonable payback period of approximately 8 years. Such a reduction in CO$_2$ emissions is possible by tackling the main energy consumer for hotels i.e. energy consumption for hot water. Various Energy efficiency and renewable energy combination of measures were considered in this study, however air to water heat pumps combined with roof and facade mounted photovoltaic's produced the lowest CO$_2$ emissions. Policy to achieve near zero energy/CO$_2$ emissions hotels should therefore focus on implementing renewable energy solutions for generating hot water and facilitating the transition of integrating renewable energy with the facade.

Keywords: EnergyPlus, DesignBuilder, NZEB, Zero Energy Buildings, NZCO$_2$EB

## 1 INTRODUCTION

Buildings account for around 40% of total primary energy consumption and 36% of greenhouse gas (GHG) emissions in Europe [1], which is higher than the energy consumed for transport and industry put together. In Malta, the building sector consumes about 35% of the total energy consumption [2] .The European Union (EU) has set ambitious targets to reduce the domestic GHG emissions by at least 80% by 2050 compared to 1990 levels [3] Buildings, especially high energy consumption buildings such as the hospitality sector, which accounts for 2% of the total world's CO$_2$ emissions [4], have an important role to play to meet these ambitious targets.

Hotels are very high energy consumers, with a consumption of between 200-400 kWh/m$^2$/year being reported in literature depending on the type and location of the hotel [5] [6]. However despite this high energy consumption, only a small fraction in (the range of 3-9% [5]) of their total operation cost is due to energy use, and therefore the importance of investing in energy efficient equipment and renewable energy technologies may not be given the priority it deserves by hotel owners.

However, hotel owners will soon require to give mandatory priority to the energy performance of their buildings, as Energy Performance in Buildings Directive (EPBD) recast, requires hotels, like other new buildings, to reach Near Zero Energy Buildings (NZEB) requirements by 2020 [1]. Unfortunately, as of 2016, neither the cost optimal nor the nearly zero energy performance requirements have been defined for Malta.

Furthermore, sustainable energy in hotel buildings is of paramount importance especially for the Maltese Islands so as to promote sustainable tourism. This importance is highlighted given that in 2015 the tourism industry contributed to 18.69 % of Malta's GDP in 2015 [7] compared to the 9.8 % the tourism industry [8] contributed to world GDP in 2015.

Given tourism's importance to Malta's GDP and that the hospitality sector is growing with new hotels being built or new extensions being made to existing hotels (to cater for the increased influx of tourists to the Islands [2]), it is essential that policy requirements for hotels to reach NZEB so to aid Malta reach its 2020 Renewable Energy (RE) and Energy Efficiency (EE) targets, are immediately defined.

This work extends on what has been done by [2] and applies Renewable Energy (RE) and Energy Efficiency (EE) measures on a new hotel to be built in Qala, Gozo. The study applies common EE and RE technologies available on the market to identify the theoretical minimal operational energy performance in kWh/m$^2$/year one can achieve for the new hotel building using such technologies.

Interestingly, the study uses the concept of Near Zero CO$_2$ emissions due to energy use (NZCO$_2$EB), in addition to the frequently used NZEB definition based on operational energy as defined in the EPBD recast directive [1]. This definition which has been adopted in the EU funded Near Zero $CO_2$ project [9] gives importance to the environmental impacts bases on carbon emissions of the fuel source being used.

By identifying how low we can theoretically go with our operational energy and $CO_2$ emissions for a typical hotel using RE generated from site and commonly available technology, this study will serve as an invaluable starting point for policy makers to define NZEB requirements for hotels and to identify the way forward to reach such requirements. This way forward can be identified given that this study identifies the measures that have the highest impact in reducing operational energy/$CO_2$ emissions for a typical boutique hotel building. An economic analysis based on the simple payback method to reach the lowest theoretical NZEB/ $NZCO_2EB$ is also presented.

## 2 LITERATURE REVIEW

Studies have shown that the energy consumption of a hotel may vary a lot among different locations and categories of hotels, but in general hotels are energy intensive [4]. It has also been shown in studies such as [5], [6], [10], [11], that energy for a hotel is primarily consumed in Heating, ventilation and Air Conditioning (HVAC).

## 3. HOTEL UNDER STUDY

The site of the hotel to be studied is shown in the Figure 1. As of 2016, the hotel still has not been built but has been designed and its application has been submitted and given approval by the Planning Authority. The hotel shall be located at the village of Qala in Gozo, close to a historical wind mill, which has been converted to a residence.

The hotel shall comprise of 4 levels, with the basement being a garage and storage area. It shall have a small pool and entrance garden on the front, as shown in Figure 1.

The total conditioned floor area of the hotel shall be 397.3 m² having 185.5 m² on the ground floor, 172.4 m² in the first floor and 39.4 m² on the top floor plant room.

The unconditioned space has an area of 340.1 m², thus bringing the total floor area to 737.3 m². The hotel is rated as 3-star with 6 double bedrooms. All bedrooms have with bathrooms and shower cubicles, except for one room that has a bathtub.

**Figure 1:** Pictures showing hotel and site of the hotel to be studied.

## 4 METHODOLOGY

### 4.1 Reference scenario

As a starting point, a reference scenario was chosen for the hotel. This reference scenario was based on the construction U-values as defined in the local legislation (Technical Guide F [12]).

The following construction and equipment parameters were first taken as reference:

**Construction Parameters:**

- **Roof U-Value:** 0.6 W/m2K
- **External Walls U-value**: 1.44 W/m²K
- **Glazing**: 5 mm clear glazing with aluminium frame.
- **Lighting:** High efficiency fluorescent (equivalent to T5 tubes)- 3.3 $W/m^2/100$ lux

**Equipment:**

- **Hot water**: Electric storage water heaters

**Air to Air reversible heat pump for space cooling/heating:**

- **Seasonal COP in heating**: 3.5
- **Seasonal EER in cooling**: 3.0
- Rooms were taken as **naturally ventilated** with the required Air Changes per Hour (ACH) achieved.
- Catering equipment was assumed to be electrically operated and consume 16 $W/m^2$

The reference scenario was modelled on DesignBuilder (EnergyPlus [13]) software as shown in Figure 2, with the following activity scenarios and comfort set points assumed for the simulations:

- **Rooms' occupancy times and occupational density**: defines as per UK NCM calculation schedule.
- **Hot water utilisation :** 120 litres/person/day at 65°C resulting in 1400 litres/day (total hotel hot water consumption) at 65°C (CIBSE Guide A [14] was used as a guideline)
- **Temperature set points in rooms (compliant with EN 15251** [15]**):** Heating set point 20°C, Cooling set point: 25°C

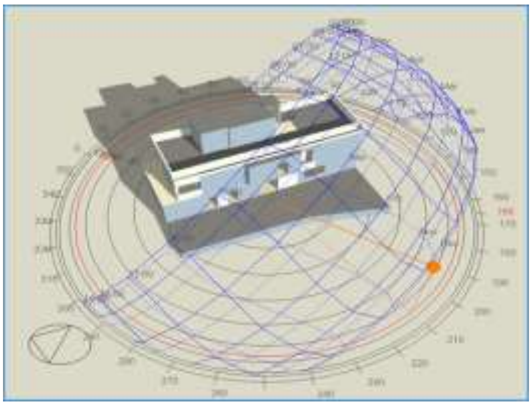


**Figure 2:** DesignBuilder model of the hotel under study

Using the parameters defined above, the hotel's site energy requirements for hot water, space heating and cooling, lighting, office equipment and catering were calculated. The total $CO_2$ emission due to operational energy was also calculated.

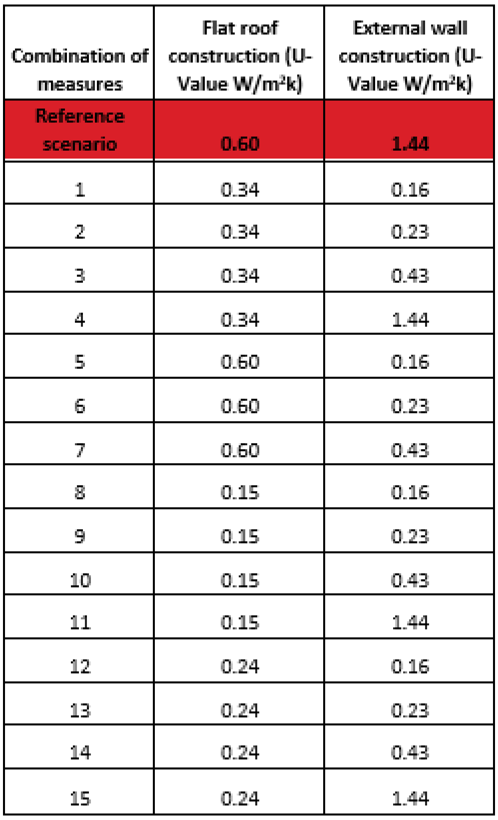
4.2 Retrofitting measures

The energy retrofitting combination of measures (EE and site RE) were than applied to the hotel reference building DesignBuilder model as described below.

*4.2.1 Roof and wall constructions improvements*

Insulation was added externally to the roof and wall of the reference scenario. The U-value combination of measures for the roof and wall constructions that were considered for this study are shown in Table 1. For each combination of measure, the building was simulated with the other parameters for equipment and glazing construction kept as per reference scenario. The operational $CO_2$ emissions for each combination of measure was recorded and compared with the reference scenario.

**Table 1:** Combination of measures considered and smulated for the roof and wall constructions



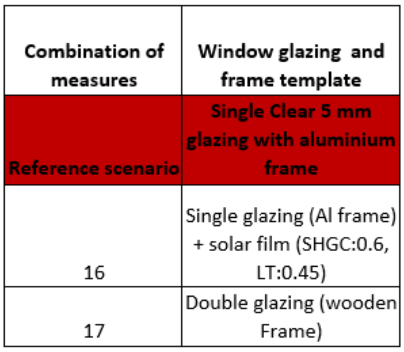
| Combination of measures | Flat roof construction (U-Value W/m²k) | External wall construction (U-Value W/m²k) |
|---|---|---|
| Reference scenario | 0.60 | 1.44 |
| 1 | 0.34 | 0.16 |
| 2 | 0.34 | 0.23 |
| 3 | 0.34 | 0.43 |
| 4 | 0.34 | 1.44 |
| 5 | 0.60 | 0.16 |
| 6 | 0.60 | 0.23 |
| 7 | 0.60 | 0.43 |
| 8 | 0.15 | 0.16 |
| 9 | 0.15 | 0.23 |
| 10 | 0.15 | 0.43 |
| 11 | 0.15 | 1.44 |
| 12 | 0.24 | 0.16 |
| 13 | 0.24 | 0.23 |
| 14 | 0.24 | 0.43 |
| 15 | 0.24 | 1.44 |

*4.2.2 Window frame/ glazing construction measures*

The next step was to identify how improvements in the window frames/ glazing constructions affect the operational energy/$CO_2$ emissions performance when compared to the reference scenario.

The roof and wall constructions were kept as per reference scenario for this analysis. The combination of measures for the window frames/glazing constructions that were considered for this study are shown in Table 2. Simulations were carried out for each combination of measures.

**Table 2:** Combination of measures considered and simulated for the window frames/glazing constructions



| Combination of measures | Window glazing and frame template |
|---|---|
| Reference scenario | Single Clear 5 mm glazing with aluminium frame |
| 16 | Single glazing (Al frame) + solar film (SHGC:0.6, LT:0.45) |
| 17 | Double glazing (wooden Frame) |

### *4.2.3 Lighting efficiency measures*

The savings in operational energy performance and $CO_2$ emissions achieved by replacing fluorescent lighting with an efficiency of 3.3 W/m$^2$-100 lux to LEDs with an efficiency of 2.5 W/m$^2$-100 lux was analysed.

### *4.2.4 Catering equipment measures*

The catering equipment which was assumed to be electrically operated and emitting 0.7394 kg/kWh of $CO_2$ emissions, was replaced with one that operates with LPG gas that generates 0.195 kg/kWh of $CO_2$ emissions. The resulting savings in $CO_2$ emissions were analysed.

### 4.3 Identifying the site RE potential

Once the above energy efficiency measures were analysed, the potential energy that can be generated from renewable sources on site was studied. A shading analysis was first carried out for the roof top to identify which parts of the roof will be shaded between 10.00 and 14.00 on 21st December. The shaded parts that resulted from this analysis were deemed not to be suitable for placing RE sources (Photovoltaics (PVs) and/or Solar water heaters (SWHs)) The shading analysis out was carried using DesignBuilder software as shown in Figures 3 and 4 below.

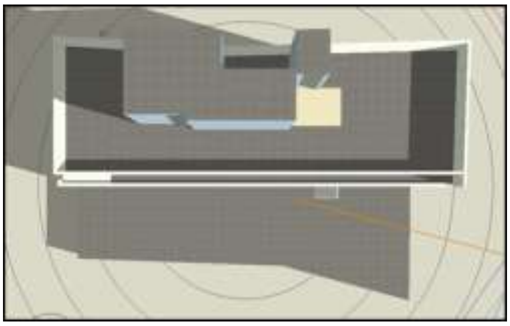


**Figure 3:** Roof shading as on 21st December at 10:00

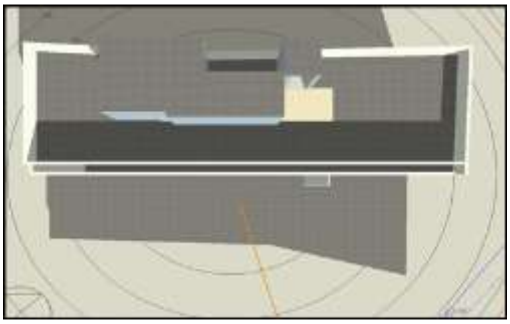


**Figure 4:** Roof shading as on 21st December at 14:00

Once the above shading analysis was carried out, the roof top area that remained available for RE panels was calculated and is shown in Figure 5. The available area for RE was found to be around 40 m$^2$ from a total roof top area of approximately 150 m$^2$.

**Figure 5:** The area (bordered in blue) left available for RE after the shading analysis was carried out

### 4.4 Hot water efficiency measures

Two energy saving options were considered for hot water:

**Option 1**: *Replacement of hot water storage heaters with air to water heat pump/s*[1] *with an assumed seasonal COP of 3*. The advantage of this option is that it does compete with PV panels for roof top space given that it can be placed also in shaded areas of the rooftop. In addition, no auxiliary source of heating is required.

**Option 2:** *Replacing hot water storage heaters with glazed SWH* [2] *and resistance heaters (as back up). A Solar Fraction (SF) of 0.8 was assumed as this SF is optimal for Malta*[16]. *An auxiliary heating source is required for this option.*

### 4.5 Mounting RE panels to the façade

The potential of RE on the upper part of façade was analysed. It was found that a total area of 96 m$^2$ of RE panels can be applied to the façade. Figure 5 depicts the total RE panels potential at the hotel, amounting to 36 m$^2$ of roof mounted RE panels at an angle of inclination of 10 degrees and 96 m$^2$ of panels applied to the façade.

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[1] Pumping power requirements for heat pumps were assumed negligible for this study.

[2] Pumping power requirements for SWH's were assumed negligible for this study. SWHs were assumed to have a Fr (tau alpha) coefficient of 0.739, Fr UL coefficient of 3.982, 5 % miscellaneos losses, storage was considered with a capacity of 75 L/m$^2$ of collector area and an 80 % heat exchager efficiency, 5 % balace of system losses were assumed.

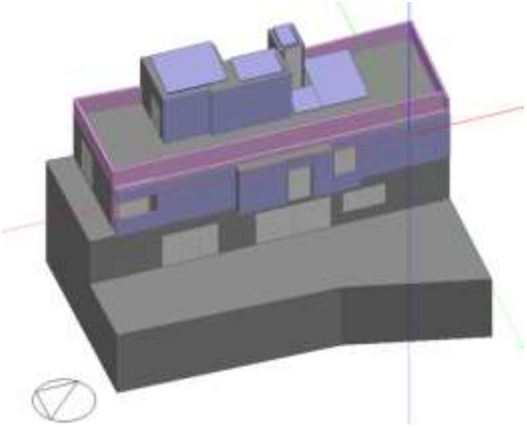


**Figure 5:** The area (bordered in blue) left available for RE after the shading analysis was carried out

## 5 RESULTS

### 5.1 Site energy consumption pattern and operating $CO_2$ emissions for the reference scenario hotel

The energy consumption pattern of the reference hotel is shown in Figure 6, where it can be clearly depicted that the major energy consumer amounting to 42 % of the total consumption is hot water. The energy consumed for space cooling contributes to almost 20 % of the total energy consumption, followed by lighting which contributes to 13 %. Office equipment and catering each account for approximately 10% of the total energy consumption of the hotel while space heating only contributes to 7% of the total energy consumption. The total energy consumption for the hotel amounts to 65 MWh per annum, equivalent to 48,000 kg of $CO_2$ emissions.

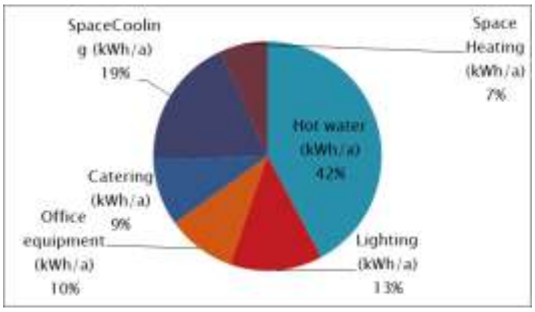


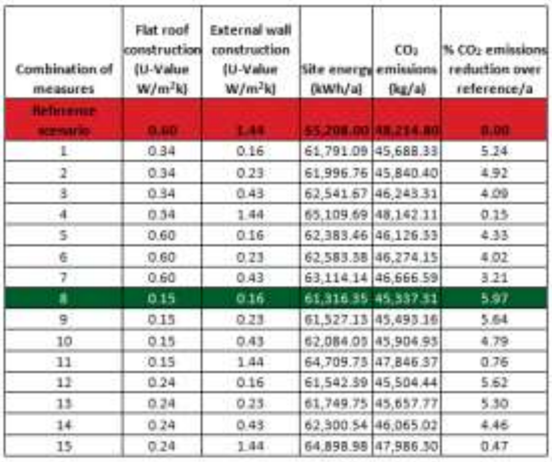
**Figure 6:** Site energy consumption for the hotel reference scenario

### 5.2 Reduction in operating CO2 emissions for the various measures

#### *5.2.1 Roof and wall constructions improvements*

Table 3 identifies the maximum % $CO_2$ emissions reduction that can be achieved by adding different levels of insulation to the external walls and roof so as to decrease their U-Values. The maximum reduction of 6 % in $CO_2$ emissions compared to the reference scenario is achieved at the lowest considered U-values for the roofs and walls i.e. when the U-value for the flat roof is 0.15 W/m$^2$k and the U-Value for the walls is 0.6 W/m$^2$k (Combination of measure no.8).

**Table 3:** % $CO_2$ emissions reduction over reference achieved for different combinations of walls and roof U-values



| Combination of measures | Flat roof construction (U-Value W/m$^2$k) | External wall construction (U-Value W/m$^2$k) | Site energy (kWh/a) | $CO_2$ emissions (kg/a) | % $CO_2$ emissions reduction over reference/a |
|---|---|---|---|---|---|
| Reference scenario | 0.60 | 1.44 | 65,208.00 | 48,214.80 | 0.00 |
| 1 | 0.34 | 0.16 | 61,791.09 | 45,688.33 | 5.24 |
| 2 | 0.34 | 0.23 | 61,996.76 | 45,840.40 | 4.92 |
| 3 | 0.34 | 0.43 | 62,541.67 | 46,243.31 | 4.09 |
| 4 | 0.34 | 1.44 | 65,109.69 | 48,142.11 | 0.15 |
| 5 | 0.60 | 0.16 | 62,383.46 | 46,126.33 | 4.33 |
| 6 | 0.60 | 0.23 | 62,583.38 | 46,274.15 | 4.02 |
| 7 | 0.60 | 0.43 | 63,114.14 | 46,666.59 | 3.21 |
| 8 | 0.15 | 0.16 | 61,316.35 | 45,337.31 | 5.97 |
| 9 | 0.15 | 0.23 | 61,527.13 | 45,493.16 | 5.64 |
| 10 | 0.15 | 0.43 | 62,084.05 | 45,904.93 | 4.79 |
| 11 | 0.15 | 1.44 | 64,709.73 | 47,846.37 | 0.76 |
| 12 | 0.24 | 0.16 | 61,542.39 | 45,504.44 | 5.62 |
| 13 | 0.24 | 0.23 | 61,749.75 | 45,657.77 | 5.30 |
| 14 | 0.24 | 0.43 | 62,300.54 | 46,065.02 | 4.46 |
| 15 | 0.24 | 1.44 | 64,898.98 | 47,986.30 | 0.47 |

This relatively low percentage in $CO_2$ emissions reduction is mainly due to the fact that the climate in Malta is mild unlike Northern Europe.

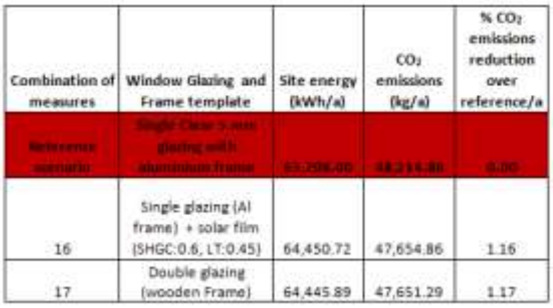
It must be noted however, that for the coldest (design) week in winter, upgrading the building to combination of measure no. 8 from the reference scenario results in 59.5% heat energy savings during that week. For the summer hottest (design) week, upgrading the building to reference scenario 8 will result in 20.8 % cooling energy savings during that week. In addition, such upgrade will reduce the heating design sizing load of the heat pump by 30 % and the cooling design sizing load by 19.4 %, which means there is a there is potential reduction in the capital cost of the heat pump equipment when increasing insulation to the walls and roofs.

### *5.2.2 Window frame/ glazing construction measures*

The % $CO_2$ emissions reduction that is achievable from the reference scenario by improving the wall/glazing constructions is shown in the table 4 below. The roof and wall insulation and equipment are kept as per reference scenario.

Results indicate that it does not make economic sense in investing in high performance windows, given that the hotel rooms have a small glazing to wall ratio (30%), and that rooms are only occupied during night time hours and early morning hours.

**Table 4:** % $CO_2$ emissions reduction over reference achieved for different wall frame/glazing combination of measures



| Combination of measures | Window Glazing and Frame template | Site energy (kWh/a) | $CO_2$ emissions (kg/a) | % $CO_2$ emissions reduction over reference/a |
|---|---|---|---|---|
| Reference scenario | Single Clear 3 mm glazing with aluminium frame | 65,208.00 | 48,214.80 | 0.00 |
| 16 | Single glazing (Al frame) + solar film (SHGC:0.6, LT:0.45) | 64,450.72 | 47,654.86 | 1.16 |
| 17 | Double glazing (wooden Frame) | 64,445.89 | 47,651.29 | 1.17 |

**Table 5:** % $CO_2$ emissions reduction over

| Combination of measures | Lighting Template | Site energy (kWh/a) | $CO_2$ emissions (kg/a) | % $CO_2$ emissions reduction over reference/a |
|---|---|---|---|---|
| Reference scenario | high efficiency fluorescent lighting | 65208.00 | 48860.35 | 0.00 |
| 17 | LED | 63065.67 | 46630.76 | 3.29 |

### *5.2.3 Lighting efficiency measures*

The effect on energy performance and $CO_2$ emissions in replacing high efficiency fluorescent lighting with LED lighting with an efficiency of 3.3W/$m^2$-100 lux is shown in Table 5 below. All other parameters are kept as per reference scenario.

A 3.3 % savings in CO2 emissions results by simply installing LEDs instead of fluorescent lighting. LEDs also have the added advantage of a longer lifetime.

### *5.2.4 Catering equipment measures*

The total $CO_2$ emissions saved by replacing catering equipment that operates on electricity with one that operates on LPG is 3,333.4 kg $CO_2$ emissions/annum, despite that the same site energy consumption is utilised.

### 5.3 The site RE potential

The following options can be considered for the site RE potential:

### **5.3.1** *Option A - All RE panels are Photovolatiacs (power density 187.5 $W_p/m^2$)*

**Roof mounted PV system** : Total PV area is 36 $m^2$ with an azimuth of 30° and 10° inclination . The expected output is is calculated to be 1,500 kWh/$kW_p$ per annum (from RetScreen [17]) for crystalline PVs, which equates to 10,125 kWh or 7,486.43 kg of $CO_2$ offset per annum.

**Facade Building Integrated PVs (BIPVs)**: Total PV area is 96 $m^2$ amd azimuth of 30° . Expected output is 900 kWh/$kW_p$ per annum from RetScreen [17]), which equates to 16,200 kWh or 11,978.28 kg of $CO_2$ offset per annum.

### **5.3.2** *Option B - Roof RE panels are PVs (power density 187.5 $W_p/m^2$), SWH on facade is used to satisfy a* solar fraction (*SF) of 0.8, rest of facade is used for PVs*

If one had to consider, the facade RE panels to be glazed SWH, then 70 $m^2$ of glazed panels would be required to satisfy a SF of 0.8. Therefore, there will still be space for 26 $m^2$ of PV panels that can be integrated on to the facade. For this scenario the total RE potential is as follows:

**Facade:** SWHs on facade generate 22,000 kWh of energy (for hot water). The 26 $m^2$ of PV panels at azimuth of 30° have an expected output of 900 kWh/$kW_p$ per annum. The resulting energy generation of PVs equates to 4,387.5 kWh. The total $CO_2$ emissions per annum offset by RE panels (SWHs and PV panels) integrated on to the facade therefore amounts to 19,510.92 kg.

**Roof mounted PV system** : Total PV area is 36 $m^2$ with an azimuth of 30° and 10° inclination . The expected output is is calculated to be 1,500 kWh/$kW_p$ per annum (from RetScreen [17]) for crystalline PVs, which equates to 10,125 kWh or 7,486.43 kg of $CO_2$ offset per annum.

### **5.3.3** *Option C - Roof RE panels are SWH to satisfy a SF of 0.8, PVs (power density of187.5 $W_p/m^2$) are installed only on the facade*

**Facade Building Integrated PVs (BIPVs)**: Total PV area is 96 $m^2$ amd azimuth of 30° . Expected output is 900 kWh/$kW_p$ per annum from RetScreen [17]), which equates to 16,200 kWh or 11,978.28 kg of $CO_2$ offset per annum. to 16,200 kWh or 11,978.28 kg of $CO_2$ offset per annum.

**Roof mounted SWH:** To achieve a SF of 0.8, it was estimated from RETScreen using a collector tilt of tilt of 45° and a 30 ° azimuth, that 36 $m^2$ of glazed collector area is required. This will occupy the whole un-shaded roof space.

## 6. COMPARISON

The variants (combination of measures) shown in Table 6 were considered to reduce operational $CO_2$ emissions of the hotel. Improvements in the envelope were not considered, as the results have shown that these improvements are only minor compared to the savings that can be achieved by reducing the energy consumption for hot water and using RE sources. LEDs were considered to be the automatic choice considered for lighting. The resulting $CO_2$ emissions for each variant due to energy use are shown in the Table 6. The lowest $CO_2$ emissions are achieved by using scenario 4 which uses an air to water heat pump for water heating and both roof and facade mounted PVs (as per RE panels option B). Such scenario results in 77.96 % of energy saving when compared to the reference scenario.

Integrating an electric heat pump instead of the electric resistance heaters as a back-up to scenario 5 would have given similar results to scenario 4 for $CO_2$ emissions, at a larger capital cost.

## 7. ECONOMICAL ANALYSES FOR SCENARIO NO. 4

Assumption is that all energy generated from PVs is used directly in the building.

The fuel cost/annum for scenario 4 is as follows:

- Electricity cost/a: 13,899.1 kWh x €0.15/kWh = € 2,084.86/a
- Gas cost/a : (6,362.67 kWh /13.6 kWh/kg) = 464 kg @ Euro 1.45/kg = € 672.80

Total savings in fuel costs from reference per annum: € 7,374.99 per annum

O&M costs/ annum from reference scenario:

PVs (assumed 1 % of capital costs): € 396

Heat pump (assumed 2 % of capital costs): € 480

Total operational cost/annum reduction over reference (with fluorescent light and no PVs): € 6,948.99

Total investment cost (Cost of replacing fluorescent with LEDs not considered):

PVs at €1,600/kWp = = 24.75 kWp x €1,600 kWp = € 39,600

Heat pump capital cost (rough estimate): € 24,000

Total capital cost = € 63,600

Simple Payback period over reference scenario (with fluorescent light and no PVs): 9.157 years

**Table 6:** Variants considered to reduce operational $CO_2$ emissions for the hotel

| **Scenario No.** | **Combination of measures to NZCO2 EB** | **Site energy (kWh)cons. without PVs** | **Hot water site energy consumption (kWh)** | **CO2 emissions (kg) without PVs** | **Maximum CO2 emissions offset using by PVs** | **Resulting CO2 emissions from building** |
|---|---|---|---|---|---|---|
| 1 | Reference scenario (with LEDs) - No PVs | 63,065.67 | 27,500 | 46,630.76 | | 46,630.76 |
| 2 | Reference scenario with LED and electric water storage heaters replaced with air to water heat pump + PVs on facade and roof (Option A) | 44,732.34 | 9,166.67 | 33,075.09 | 19,464.71 | 13,610.38 |
| 3 | Reference scenario with LED and electric storage water heaters replaced with SWH (SF of 0.8) on roof + electric back up+ PVs on facade (Option C) | 41,065.67 | 5,500.00 | 30,363.96 | 11,978.28 | 18,358.68 |
| 4 | Reference scenario with LED , electric water storage heaters replaced with air to water heat pump, + PVs on facade and roof (Option A), LPG catering equipment instead of electrical equipment | 44,732.34 | 9,166.67 | 29,741.69 | 19,464.71 | 10,276.98 |
| 5 | Reference scenario with LED , electric water storage heaters replaced with SWH (SF of 0.8) on roof, + electric back up+ PVs on facade (Option C)+ LPG catering equipment instead of electrical equipment | 41,065.67 | 5,500.00 | 27,030.56 | 11,978.28 | 15,052.08 |
| 6 | Reference scenario with LED, SWH (SF of 0.8) on facade + electric back up+ 26 m$^2$ of PVs on facade + roof mounted PVs (Option B), LPG catering equipment instead of electrical equipment | 41,065.67 | 5,500.00 | 27,030.56 | 10,730.54 | 19,633.42 |

## 8. CONCLUSION

It has been shown, that one can reduce the operating $CO_2$ emissions by more than 75% for a small hotel building when compared to a reference scenario. Such reductions can be achieved with a reasonable pay back period of approximately nine years if one identifies and studies different combination of EE and RE measures and then carefully chooses the most appropriate measures technologies for his specific scenario. Reducing energy consumption from the main energy consumer (hot water) is the key to reducing $CO_2$ emissions in hotel buildings and therefore RE sources (Heat pumps and/or SWH) for producing hot water should be given prioity in terms of policies for hotel buildings.

This study has shown that air to water heat pumps combined with photovoltaics have a huge potential in reducing the $CO_2$ emissions for a small hotel in order to achieve $NZCO_2EB$ status. Thus this technology should be further promoted for policy measures.

The results obtained for scenario 4 do not produce exact zero $CO_2$ emissions from the Gozo hotel building. It must be noted however, that COPs for space heating and cooling heat pumps are improving, and seasonal COPs/EER of 4.5 and 4 are becoming more common. However, performance data specific for Malta is required to verify these COPs for the heat pumps. Other approaches to improve COPs may involve the use of ground source heat pumps, which are currently (2016) being further researched in Malta. In addition, increased generation from PVs may be carried out by using solar optimisers or micro inverters in partially shaded areas of the roof top.

This means that a zero $CO_2$ hotel building is theoretically possible, if more state of the art technologies are used. The results show however that in order to achieve zero $CO_2$ emissions from small public hotels, RE must also be applied to the facade and not only limited to the roof top.

Finally, as was also shown in this study choosing equipment that operates with gas instead of electricity can result in a significant reduction in $CO_2$ emissions despite no reduction in site energy.

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