Which renewable energy mix to ensure zero energy in apartment buildings. The case study of Belas Clube de Campo

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Extended Abstract

This document aims to assess which is the renewable energy mix that makes the case study as a zero-energy building. This mix should consider the production of renewable energy on site, allowing each of the apartments to meet its electrical and thermal comfort needs. The case study is a building located in *Belas Clube de Campo*.

The estimation of the energy consumption of the apartments used the list of electrical equipment present in the apartments and in the energy certificates. Assumptions were made regarding the annual estimation of the electrical consumption of equipment. The same process was applied to the lighting equipment. The renewable energy calculations were based on data retrieved from the software PVGIS and MERRA-2, where 11 years of data were retrieved with hourly average values, with the processing of the data allowing the creation of an annual distribution for a typical year.

Several mix proposals were considered, with the objective to compare them and assess their economic viability.

This analysis concluded that the case study reaches the zero-energy, having a residual fossil fuel dependency of 4% and considering the Portuguese legislation published in April 2 of 2019. The optimal mix makes use of wind, solar photovoltaic and solar thermal technologies.

Keywords: Zero-energy, Renewable Energy, Economic Feasibility, Self-sustainability

1. Introduction

1.1. Context

Climate change is the main factor that contribute for the increase in installations of renewable energy sites as an effort to reduce the dependency on fossil fuels, increasing the diversity of energy production technologies while reducing the Green House Gases (GHG) emissions.

In 2015, renewables accounted for 70% of total electricity generation investment, led by wind power (37%), solar PV (34%) and hydropower (20%). China was the biggest investor ($90 billion), followed by the European Union ($56 billion) and the United States ($39 billion) (IEA, 2016).

The residential sector is one of focal points for the energy efficiency that translates into 20% savings target by 2020, since it was responsible for around 16% of the final energy consumption of the country in 2016. In the EU-28 and in the Euro Area 19 (EA19), the sector accounted for 26% and 24% respectively (PORDATA, 2016). Ever since the EU adopted the Energy 2020 objectives in 2007 (European Commission, 2010), the data gathered showed a slightly decreasing trend in the consumption of final energy in the residential sector, which seems to confirm the effort made by the countries part of the EU-28 to accomplish the targets they imposed for 2020, as can be seen in Figure 2. Portugal has shown a similar trend, reinforced by the legislation in place, regarding the National System for Energy Certification and the Regulation for the Energetic Performance of Buildings.

The approval of law decree nº118/2013, that amends the previous one (law decree nº80/2006), states that it is mandatory for a new building to have solar thermal systems for Domestic Hot Water (DHW). Although there are a few exceptions that allow a building to overrule this law, most of the buildings are subject to this legislation.

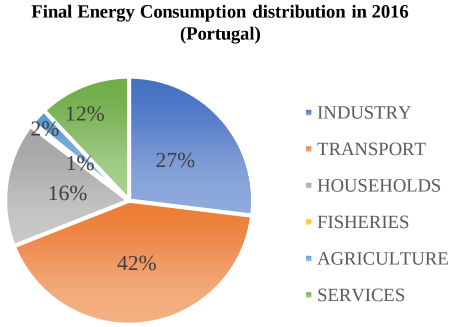

Figure 1-Final energy consumption distribution in 2016 for Portugal (PORDATA, 2016).

1.2. Objective and Hypothesis Review

This document pretends to assess if the case study can have a zero-energy balance, assisted by a renewable energy *mix*. The proposals should be economically viable and have a low fossil fuel dependency.

The results are then compared with the Portuguese legislation, that establishes the parameters that a near zero-energy building should have. This legislation (Portaria n.o 98/2019) was published in the 2nd of April of 2019 (DR, 2019).

Methodology

Knowing the location of the case study one could argue that measures should have been made regarding the solar irradiance and wind speed conditions on site, to obtain the data needed for the calculations of the production capabilities of the location. Since, ideally, hourly data should be provided to have an estimate of the variations of these variables throughout the year, this approach would take a considerable amount of time.

The work developed in this case study was based on the data provided by MERRA-2 (Gelaro et al., 2017) and PVGIS (European Commission, 2018) from the European Commission.

The data collected comprise values from the years of 2007 until 2017 to get a more robust set of data. Since the average values of irradiance and wind speed for the 8760 hours of the year were considered for the calculations of the generation of energy.

Since the object of study already has installations of thermal solar energy conversion equipment, this study only considered the integration of small wind turbines and photovoltaic solar panels.

The approach used for the photovoltaic followed the ideal model of a photovoltaic cell, described as the three parameters model in *Validation of Photovoltaic Electrical Models against Manufacturers Data and Experimental Results* (Crispim, Carreira, & Rui, 2007), while for the small wind turbines, several equipment was considered (the most common brands in Portugal), and their power curves was used for the calculations of the renewable energy potential.

For the consumption of the apartments, several assumptions were made, to get a rough estimation of the electrical energy needs.

The establishment of the renewable mix was done considering several case scenarios, where different PV panels and small wind turbines were considered, to obtain an idea of the conditions that allow such project to be economically viable.

2. Literature review

In (Li, Yang, & Lam, 2013) it was stated that the Zero Energy Buildings (ZEB's) studied in the document used some sort of PV technology to account for their energy needs. The application of Building-integrated photovoltaic (BIPV) increased the power generated per unit floor area of the building, however affected the natural daylight penetration. Regarding the wind turbines the authors stated that, in general, solar and wind availability tends to have some complementary characteristics, since in many cases when solar availability is low, wind availability is high, and vice versa. However, this complementary depends on the site, since buildings placed in unobstructed locations can benefit from solar and wind at the same time.

In (Wang, Gwilliam, & Jones, 2009) the authors concluded that in the UK, it is theoretically possible to achieve zero energy homes, through the utilization of PV and Wind turbine systems. The study showed that the annual production of electricity from solar and wind resources surpassed the electrical demand.

The study conducted by (Marszal et al., 2011) concluded that ZEB's have the promising potential to significantly reduce the energy use and as well to increase the overall share of renewable energy. The authors mentioned issues regarding large storage capacity, backup generators and energy losses due to storing or converting energy. These issues are the main factors that impose difficulties in implementing off-grid ZEB's.

The paper (Orehounig, Evins, & Dorer, 2015), describes the application of an energy hub concept at urban level, considering the integration of decentralized energy systems at building and neighborhood scale. The authors concluded that this method has the advantage of not only integrating the technologies at building level but various technologies both decentralized and locally, which enables the energy to be shared amongst various consumers and producers. The challenge consists on having multiple renewable energy sources and make a resilient system, due to the intermittence of such energy sources.

3. Case Study

3.1. The building

As it was mentioned, the case study is an apartment building located in Lisbon Green Valley by Belas Clube de Campo, on the outskirts of city of Lisbon, in the municipality of Belas in Sintra county. The apartments have an energy certificate of A (second highest on a scale between F and A+) and a sustainability certificate of A+ (also the second highest on a scale between G and A++) (LiderA, 2018).

The building is composed of 16 apartments, divided in four floors. The typologies of the apartments are divided in two T1, six T2 and eight.

There are two T3 apartments in each floor, while the T1 are situated in the floor 0, and the T2 in the remaining three floors.

Each apartment is equipped with air conditioners in the living room and each of the bedrooms. Each has at least one solar collector for DHW (the T3 have 2 collectors dedicated), a natural gas boiler (27,4kW) for DHW and the underfloor heating.

The list of the electrical equipment present in the apartments was given by Real Estate Agency - *Planbelas Sociedade Imobiliária S.A.* and can be seen in the table 1 below.

Table 1-Electric equipment list of each apartment

Electrical equipment	Power (*W*)
Exhauster	250
Induction plate	6000
Electric Oven	3380
Microwave	1270
Freezer	120
Fridge	90
Dishwasher	800
Clothes washing machine	500
Drying machine	2800
Electric towel rails	300

The equipment listed above comprises the equipment that is available in all the apartments (the number of electric towel rails directly relates to the number of bathrooms in each apartment), not counting other electric equipment (TV, PC's, etc) that might exist in the apartment after a person moves in.

Figure 2-Exterior view of the building

The front of the building is west oriented, meaning that it gets, in average, half a day of solar exposure.

3.2. Renewable resources

The data gathered in PVGIS (European Commission, 2018) and MERRA-2 (Gelaro et al., 2017), consisted in hourly time steps for one year, where 11 years were considered (2007-2016).

The data used in the computation model consisted on the variation of the daily solar irradiance and wind speed in a typical day of every month, comprising 288 values of each (24 hours X 12 months).

4. Energy computation

4.1. Solar photovoltaics

As it was mentioned in the methodology section, the computation of energy generation was based on the ideal model (three parameters model) presented in *Validation of Photovoltaic Electrical Models against Manufacturers Data and Experimental Results* (Crispim et al., 2007).

The ideal model was chosen for its simplicity and fast parameter computation, while not adding a huge error when compared to more complex models as the four-parameter model or de five-parameter model. The ideal model structure of a typical silicon PV cell is depicted in Figure 3.

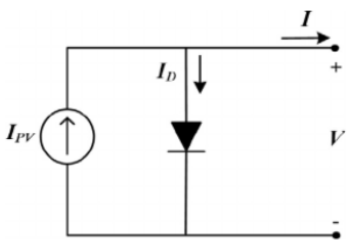

Figure 3-Equivalent circuit of a PV cell according to the ideal model

The maximum power output is simply the product of the maximum current with the maximum voltage, which can be written:

$$P_{MP} = I_{MP} \times V_{MP} \qquad (1)$$

The equations that describe the maximum current and the maximum voltage present in the equation (1) can be written as:

$$V_{MP} = mVt \ln\left(\frac{\frac{I_{SC}}{I_0}+1}{\frac{V_{MP}}{mVt}+1}\right) \qquad (2)$$

$$I_{MP} = I_{SC} - \left[I_0 \left(e^{\frac{V_{MP}}{mVt}} - 1 \right) \right] \qquad (3)$$

The equations (2) and (3) are computed using values in the conditions of irradiance and ambient temperature at a given moment.

Having the equations needed for the computation of the maximum power output, we can calculate the energy delivered by the PV module:

$$E = \eta_{total} \sum_{i=1}^{n} P_{DC}(G, T_{amb})_i \Delta t_i \qquad (4)$$

The P_{DC} is the same quantity as P_{MP}, since the PV module rely on a device called the Maximum Power Point Tracker (MPPT), which guarantees that the output DC power is always the maximum possible. The η_{total} is the sum of the inverter efficiency and the MPPT efficiency. Since the MPPT efficiency is always very high, for the sake of simplicity it was considered as unitary. So η_{total} corresponds to the inverter efficiency. The inverter considered is monophasic and has an efficiency of 97%.

4.2. Small wind turbines

Regarding the small wind turbines, several brands available in Portugal were considered and their power curve was obtained through the consultation of their datasheet. An example can be seen in Figure 7. Having the power curve, it is possible to know the power output of the wind turbine for each wind speed.

The energy output for each wind speed is then given by:

$$E = \sum_{i=1}^{N} P(v)_i \times nh_i \qquad (5)$$

Where P(v) is the output power for a given wind speed and nh is the frequency occurrence of the respective wind speed in hours, in a year.

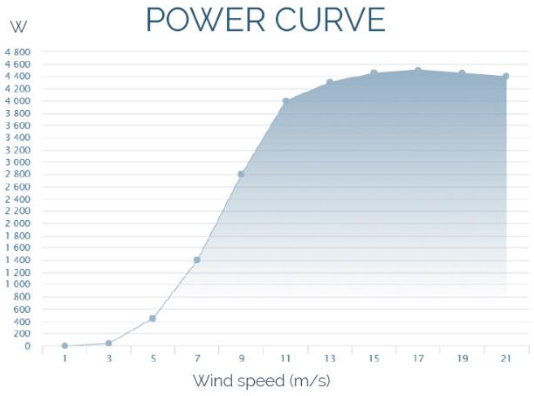

Figure 4-Example of a wind turbine power curve (ENERGY, 2018)

5. Building consumption

Having the list of the electrical equipment present in every apartment, a few other equipment was considered to have a rough estimate of the electrical consumption. Through a list given by the Real Estate Agency, it was possible to conduct an analysis for each apartment, since the electrical equipment present on each of them was the same.

For each apartment typology, the number of people assumed was:

- T1 typology has 2 people living;
- T2 typology has 3 people living;
- T3 typology has 4 people living.

The number of people was important to estimate the number of some electric equipment present in the household (PC's and smartphones), since we allocated one of each of these equipment per person. For the sake of simplicity, it was considered that these values are constant for every week of the year.

The lighting uses LED lamps of 7 W and their amount per apartment can be consulted in the Table 2. It's important to mention that the T3 typology on the zero floor has more LED lamps in the exterior since it has a garden. The other T3 in the remaining floors only have balconies.

For the sake of simplicity, it was considered that these values are constant for every week of the year.

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Regarding the comfort needs (cooling and heating needs) and the DMW, the energy certificate provided the information needed. We can then get a rough estimate of the electricity consumption based on that and considering the presence of air conditioners in each bedroom and in the living room.

Table 2-Weekly utilization of electric equipment considered.

Equipment number	Eletrical equipment	Utilization per week (h)
1	Exhauster	7
2	Induction plate	7
3	Electric Oven	2
4	Microwave	0,5
5	Freezer	168
6	Fridge	168
7	Dishwasher	4
8	Clothes washing machine	3
9	Drying machine	3
10	Electric towel rails	3,5
11	TV	28
12	Vacuum cleaner	2
13	Handheld vacuum cleaner	0,5
14	Hair dryer	1,75
15	Toaster	1:10
16	Coffee machine	1:10
17	PC's	27
18	Smartphones	10:30
19	Electric iron	2

The certificate provides information on the cooling and heating and DMW needs in kWh/m^2.year, which were transformed in kWh/year, by multiplying the useful area of the apartment.

The methodology established for the estimation of energy consumption, consisted in considering the heating and cooling needs assessed in the apartment by the certificate and later subtracted the annual estimated production of these energy needs by the equipment present for that purpose (also present in the certificate). Firstly, we have the DMW needs, in kWh/year and knowing the estimated production of thermal solar system and natural gas boiler, we subtract both production estimates to the needs. The same is applied for the heating needs since the certificate accounts for the presence of the underfloor heating which is also fed by the boiler.

For the cooling needs, the apartment plants provided information regarding the presence of air conditioners present in the rooms.

Table 3-Annual electric consumption

Floors	Typology	Final electric consumption (kWh/year)
Zero floor	T3	7416
	T1	7150
	T1	6698
	T3	7236
First floor	T3	7395
	T2	7084
	T3	7293
	T2	7046
Second floor	T3	7414
	T2	7077
	T3	7380
	T2	7102
Third floor	T3	7208
	T2	7056
	T3	7240
	T2	7056

Since the heating needs are not fully covered by the underfloor heating, the air conditioners were assumed to compensate for this shortage.

The electricity consumption of the air conditioners is later considered as part of the electrical consumption of each apartment, being

summed to the consumption of the electrical equipment.

According to the consumptions assessed and considering the assumptions made, the apartments had (on average) 78% of electric needs for various purposes, while the DHW accounted for the remaining 22%. The lowest percentages (in both categories) accounted for 75% of electric needs in half of the apartments and 14% of DMW. The highest percentages accounted for 86% of electric needs and 25% of DMH.

Regarding the typology of each apartment, the T1 typology registered the highest percentages for electric needs (85% and 86%), having the remaining 14% and 15% for DHW. The T2 typology registered 80% for electric needs and 20% for DMH, while the T3 accounted for 75% of electric needs and 25% for DHW.

Performing the same analysis by floor, the calculations concluded that the ground floor accounted for higher electric needs, with an average of 80% while the remaining floors had a smaller share, with 78%.

6. Renewable energy mix

To determine the renewable energy mix that could enable the potential for zero energy in the building of this case study, a methodology needed to be defined. First, it was assigned a wind turbine per apartment and the surplus was covered by PV. However, several cases were considered, as it was mentioned in section 1.3.

As an example, let's consider two cases. On the first case, we subtract the power generation of the wind turbine (described in section 4,2) to the final energy consumption, listed in table 3. After that, the surplus is generated, from which the number of PV panels (in this case the area of the PV panels) needed was allocated to achieve a difference between production and consumption of zero. Since the number panels computed is not an integer, this value is rounded up, meaning that there all always enough panels to satisfy the demand calculated.

For the second case, two wind turbines per apartment were considered and the remaining process of allocation of PV panels stayed the same.

These two approaches served as comparison between having less wind turbines, and more PV panels and having more wind turbines and less PV panels, to get a measure of the conditions that make such a project economically viable.

Other differences between cases is the change in rated power of both technologies and the brand of the equipment.

The differences between the ten cases considered can be seen in the table 4, where it is first mentioned the wind turbine applied and then the PV panel.

Table 4-List of cases considered.

Case nr.	Equipment (Rated power [W])	Nr. of equipment
1	ENAIR E70 PRO (5000)	16
	MPRIME G Series 4BB 250 (250)	70
2	ENAIR E70 PRO (5000)	16
	MPRIME G Series 4BB 265 (265)	67
3	ENAIR E30 PRO (3000)	16
	MPRIME G Series 4BB 250 (250)	127
4	ENAIR E30 PRO (3000)	32
	MPRIME G Series 4BB 250 (250)	16
5	ENAIR E30 PRO (3000)	32
	MPRIME G Series 4BB 265 (265)	16
6	ENAIR E30 PRO (3000)	16
	MPRIME G Series 4BB 265 (265)	118
7	Bornay PLUS 25,2+ (3000)	16
	AXITEC AC-300T/156-60S (300)	116
8	Bornay PLUS 25,2+ (3000)	32
	AXITEC AC-300T/156-60S (300)	21
9	Bornay PLUS 25,3+ (5000)	16
	AXITEC AC-300T/156-60S (300)	76
10	Aeolos V5kW (5000)	16
	AXITEC AC-300T/156-60S	47

7. Economic Assessment

7.1. Methodology

To assess the viability of the project, an economic assessment is essential. For this purpose, this document makes use of the Net Present Value

(NPV), which is a common practice in most investments.

To use the NPV, it is mandatory to know the costs of capital (investment costs) and the costs of operation and maintenance (O&M).

For the investment costs, the methodology applied in this case study followed the information obtained from various sources, mainly reports from renewable energy agencies. For the small wind an investment cost of 3840 €/kW and 0,03 €/kWh for the O&M was considered (IRENA, 2012). For the photovoltaics, the investment cost was 2555 €/kW and the O&M costs were considered to be 1% of that investment (IEA, 2014), (IRENA, 2015), (IEA PVPS, 2015)).

Having the investment and the O&M costs, the next step is to obtain the actual savings from installing the renewable energy equipment. For that we gathered the electricity costs for 2018, provided by EDP. Assuming a simple tariff and a contracted power inferior to 6,9 kVA, the electricity costs are 0,1646 €/kWh (EDP, 2018).

Knowing the price per kWh and the energy produced in a year, by multiplying these two quantities we get an idea for the actual savings per year in electricity costs. These savings start from year 1 until year 30 since the equipment was considered to have 30 years of life expectancy. To these savings it is necessary to subtract the annual O&M costs to reach the annual net income.

The equation 6, describes the formula adopted for the NPV.

$$NPV = \sum_{j=1}^{n} \frac{R_{Lj}}{(1+a)^j} - \sum_{j=0}^{n-1} \frac{I_j}{(1+a)^j} \tag{6}$$

Where n is the number of years of life expectancy of the project, R_{Lj} is the annual income, It is the investment cost and a is the discount factor.

After the computation of the NPV, one other important quantity needed to be computed to measure the degree of viability for each case, the Return Period (RP) adopted from (Castro, 2011).

$$Tr = \frac{\ln\left(\frac{R_L}{R_L - a \times It}\right)}{\ln(1+a)} \tag{7}$$

Where R_L is the net revenue per year, It is the investment cost and a is the discount factor.

7.2. Results and discussion

The calculations described in the section 4 for the cases considered and later the addition of the economic assessment described in section 7.1, showed interesting results.

From the case studies considered, only three of them (cases 3, 6 and 7) are economically viable. These three cases share common characteristics that allow them to be viable. For starters it seems that allocating one small wind turbine of 3000 W of rated power per apartment, is the main contribute for the economic viability of this project.

The higher investment costs (Capex) appear to be the main factor for the worst results in these three cases. These options had the higher O&M costs computed, being 3744 €/year for case 4, 3751 €/year for case 5 and 3386 €/year for case 8. These results were expected, since we have more small wind turbines, hence a bigger O&M cost.

For this case study the optimal renewable mix is the one present in case 3, which comprises the installation of one small wind turbine of 3000 W per apartment and 127 PV panels of 250 W.

The case 6 also presents itself as good as case 3, with a slightly smaller NPV. The renewable mix in this case is comprised of one small wind turbine of 3000 W per apartment and 118 PV panels of 265 W.

8. Conclusions

According to the hypothesis established in the introductory section, the building can be classified as having a zero-energy balance, from which its necessities are all accommodated by making use of renewable energy harvested in the neighbouring area. According to the Portuguese legislation, the building can be classified as near zero-energy.

From the ten scenarios of renewable energy *mixes* presented, three of them are economically viable, which supports the hypothesis established. However, the return periods are very high (20+ years), getting near the values assumed for duration of the equipment (25 years).

For future work it is recommended that a better understanding of the consumption behaviours should be established, by performing enquiries to household members, since the last enquiry made in Portugal has several years and is considered obsolete. The study of batteries and electric cars should be considered, since they can change the energy balance of the case study, and in case of the batteries can have a direct influence in the consumption patterns here established. The yearly increase of the price of electricity should also be considered, since for this case study it was considered constant over the 25 years.

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