

# Optimization of integrated renewable energy system supplied for Net Zero Energy Buildings

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The European Union launched the EU Directive 2010/31, which states that all new buildings have to be nearly Net Zero Energy Buildings (NZEBs) by December 31<sup>st</sup> 2020. However, each member state has to take its own approaches in order to define NZEB term, as well as how to implement these buildings. The main interest of this work is to study possible NZEB implementations for Portugal and to define a valid framework for the term. An optimization algorithm for energy services in a given household is developed in MATLAB. It chooses the best technologies by minimizing energy consumptions and costs. The input of the algorithm via user-friendly interface takes behavioral aspects of energy consumption and available space for renewable onsite production into account. To test the constructed algorithm, different case study scenarios were performed and analyzed. It is demonstrated that the percentage of renewables present in the energy household consumption depends on the given house type and on the number of members. Thus nearly net zero apartments should include 60-65% of renewables and standalone houses 75-80%. Furthermore, it is concluded that water heating is the energy service with most unrealized saving potential and that solar thermal systems are an essential technology option to become nearly net zero.

## 1. Introduction

It is foreseen that global energy demand will increase about one third from 2011 to 2035. This corresponds to circa 4250Mtoe more energy and the related CO<sub>2</sub> emissions will rise by 20%, reaching 37.2Gt. Reasons for the increasing energy demand are mainly a tremendous population growth and an increasing income in the developing countries. The income increase may influence people's behavior as they might spend more money on energy uses, such as thermal comfort [1]. In order to satisfy the demand, all types of energy resources might have to be explored.

The European Union (EU) has surprised the International Energy Agency by reducing its foreseen energy demand for 2035 from an increase of 23% to only 13% (from 2012 Outlook to 2013). These 10% could be achieved principally due to faster growth of renewables in power generation and increased building's energy efficiency [1]. In fact, nearly 40% from the final energy consumption is attributed to the private and public building sector [2]. The EU has launched the EU Directive 2010/31 or known as EPBD (Energy Performance of Buildings Directive) recast 2010, which includes the so called Net Zero Energy concept for buildings [3]. This directive states that all new buildings have to be nearly Net Zero Energy Buildings (NZEB) by December 31<sup>st</sup> 2020 (December 31<sup>st</sup> 2018 for public authority buildings)[4].

The term of Net Zero Energy Buildings refers to buildings with highly decreased energy needs through efficiency achievement such that the balance of energy demand can be supplied by renewable technologies [2]. It is possible to find four main definitions of NZEB in the literature [3]. The most intuitive one appears to be Net Zero Site Energy which balances the produced

renewable energy with the consumed energy. In this definition, all energy is generated and consumed onsite, that is, within the buildings system boundary. Another definition is the Net Zero Source Energy which also weights the consumed energy with produced renewable energy; however the produced energy can come from out site the buildings boundary. It includes in the term of consumed energy the energy that is needed to deliver the renewable energy to the site. Net Zero Energy Cost and Net Zero Energy Emissions indicate already from their name that their weighting system is not energy based. The Net Zero Energy Cost definition balances the total energy costs with the sold energy to the grid. Finally, the Net Zero Energy Emissions balances the CO<sub>2</sub> emissions coming from energy consumption with the avoided emissions from renewables production.

To achieve NZEB implementations, each EU member state has to study its theoretical potential in order to define the term of nearly NZEB. To do so, local conditions, optimization and modeling techniques play a significant role. Portugal has not yet defined a NZEB definition. However, the country has taken some actions in order to save energy and to increase renewable onsite production such as a methodology for energy demand calculation [5] and an evaluation strategy for certifying buildings energetically. There have been promoted some programs for solar systems, in which the government supported around 50% of the acquisition costs for solar thermal systems and the installation of photovoltaics, through the implementation of feed-in tariffs.

During the last decade, the number of papers of optimization methods for renewable energy implementation in households increased exponentially. This also means that there were created innumeros

different optimization methods on the topic, depending on the approach and the chosen objective function [6]. Traditional optimization methods such as linear or quadratic optimization are able to just optimize one objective function. For NZEBs this can be energy demand, energy production, costs or CO<sub>2</sub> emissions. Linear optimization (LP) can be quite successful in this area as the authors of [7] showed. They optimized the optimal the installed capacity of a renewable energy supply system in terms of the overall costs. However, traditional optimization methods are related to quite specific cases, thus they are not universal. By considering more complex problems, that is, assuming more variables and minimizing and maximizing more than one parameter, meta-heuristic optimization approaches are necessary. Many of these optimization methods are based on natural observations and named after them. The runtimes of these programs can be very long and so it is reasonable to reduce the complexity of these methods. The input data of meta-heuristic methods regarding NZEBs are normally the climate conditions, unit prices of the projected renewable system components, including installation and maintenance costs and some constraints (such as available space for the renewable energy installation). In addition, it has to be defined the objective function(s), which in these optimizations is also called fitness function. The most used method for NZEBs is multi-objective optimization, which uses a population that evolves during the iteration process, giving a set of possible solutions. This possible set of solutions is also called Pareto set. The considered algorithm in this work is the genetic algorithm (GA). GA is an optimization method based on the genetic process in biological systems. After defining the input, GA consists in an iterative process, which includes five components: a random population generator, a fitness evaluation unit and genetic operators for “selection”, “crossover” and “mutation”. Each solution is then evaluated due to the fitness function. The genetic operator “selection” chooses the population according to their fitness. The “crossover” operator provides possible new solutions when it is needed to achieve higher fitness values and the “mutation” operator prevents the algorithm from getting stuck at a local minimum. The biggest benefit of this method is its ability to code infinite different parameters. GA is the most used optimization method in implementing hybrid systems, which are a combination of various renewable energy sources and is used by many authors. The authors [8] and [6] refer that this algorithm was used to optimize the economical design of stand-alone hybrid systems, which included as energy sources PV cells, wind turbines and fuel cells. Furthermore, [6] states that GA was used to find the optimal site for the maximum capacity outcome of wind turbines and also to evaluate costs, power production and efficiency of wind farms. The authors of [9] mention the use of GA optimization in PV systems in order to find the minimum area and maximum storage, to maximize thermal comfort, optimize power system at islands and

hybrid PV-diesel systems. All in all, it relies in the approach chosen by the system designer which optimization technique is the most satisfying for his problem.

To study Portugal’s potential for residential NZEB implementation a framework modulation, the respective code and its analysis are developed. The framework is based on the concept of energy services and optimizes different technologies and onsite renewable supply options for specific cases. Two different optimization approaches (LP and GA) are studied and used as a hybrid model. MATLAB software helps to compute the desired. The optimization minimizes the energy consumption and costs.

A comparison between different scenarios shows the best technologies for given energy services and the potential of onsite renewable implementation in Portugal.

## 2. Model programming

The modeling process involves specifying all assumption and necessary calculations made in order to formulate a goal to maximize or minimize. It also permits to present mathematically all variables and their associated constraints. In order to reach (nearly) NZEB, it should be first implemented energy efficiency measures in order to decrease energy consumption and then the energy supply. Simulating such a process is quite complex as not only the choice of renewables that are possible to install onsite as supply systems are important to develop an algorithm, but also the specific energy services, which are defined in this work as energy end-uses – Figure 1 [4], and the technologies to provide these services.

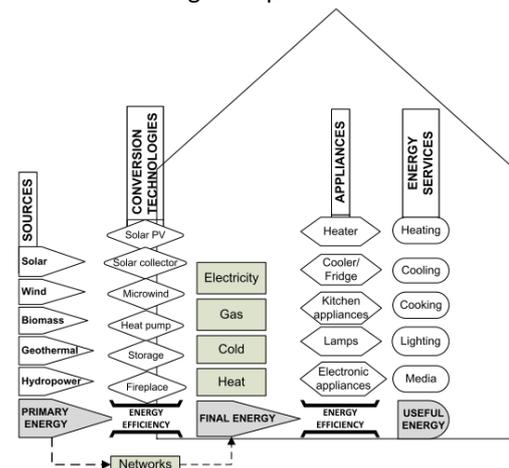


Figure 1: Model of residential end-uses and possible available energy sources [4]

The energy consumption in the considered building will depend on the installed energy services and on the occupant’s behavior. Furthermore, the implementation of renewable energy sources has the obvious advantage of energy production from our environment, without polluting it during the process. However, producing energy from renewables is a strongly climate dependent process [6]. Other important considerations as investment and maintenance costs have also to be

considered. Taking all these variables into account, it is hard to take the right decisions for each site.

## 2.1 Evaluation techniques

In order to compare different technologies for various energy services and to choose the best suited options, efficiency and optimum cost level should be considered. Normally efficiency is given in percentage, but there are some devices that have efficiencies higher than 100% like heat pumps (COP). The efficiency or COP value can be normally obtained directly from the developer.

In terms of costs, people often tend to analyze just the initial investment costs when deciding which technology they are going to buy. However, in order to optimize costs, in general it is important to consider the investment costs, the fuel costs and the operation and maintenance costs. As for instance in [11], costs are normally analyzed with the Life-cycle-cost methodology. As it is a very common practice, this work will also consider this approach. Additionally, it is developed an alternative cost analyses, the levelized cost of technology.

To get the cost level of each technology, the idea of levelized cost of energy was applied to compare different energy technologies and their according devices for a given energy service. That is, the unit price per kWh that one needs to pay for a given technology in order to reach payback inside the technologies lifetime. The levelized cost of technology LCOT can be calculated with equation (1).

$$LCOT = \frac{I_0 + \sum_{t=1}^n \frac{A_t}{(1+i)^t}}{\sum_{t=1}^n \frac{M_{t,e}}{(1+i)^t}} \quad (1)$$

where  $t$  is the year of lifetime,  $i$  the real interest rate in percentage,  $n$  the economic operational lifetime in years,  $A_t$  the annual total expenses in € in year  $t$  and  $M_{t,e}$  the consumed quantity of energy in year  $t$  in kWh.

For this cost analyses, the annual total expenses are represented by the fuel or electricity costs over the year. The LCOT value will be calculated for the lifetime of the technological equipment. The interest rate is  $i=3\%$  as the suggested value from the European Union.

As defined by [12], life-cycle cost (LCC) is the numerator of equation (1). To be a little more specific, LCC is as the name indicates the sum of all costs over a lifetime for a given technology. This value can be more or less specified and it depends on the author how exact it is determined. For this work, LCC is given in equation (2) [11].

$$LCC = I_0 + C_R + C_{O\&M} \quad (2)$$

with  $I_0$  as investment cost,  $C_R$  as the replacement cost and  $C_{O\&M}$  as the operation and maintenance costs. For the calculation of these components, a calculation period of 30 years and the effect of energy price escalation with 2% is considered.

The factor of percentage of renewables %RE is another relevant parameter. In the model, this factor will be important in order to evaluate when the chosen

technologies reach net zero. Hence all renewable devices count with 100%, electrical devices connected to the grid with %RE<sub>grid</sub> with a value of 51.91% and fuel devices with 0%. Depending on how much energy is produced by the technologies, %RE is weighted. This parameter will be essentially used to evaluate when the house is reaching a net zero balance.

## 2.2 Energy demand and given technologies

To know how much a given NZEB consumes, it is essential to estimate the energy use for all energy services. The three biggest energy consumers in the EU-27 are water heating, space heating and space cooling. One action that the EU implemented which will start in September 2015 is the labelling of all different kind of water and space heaters. The labelling will help clients to choose the best water heater not just from an economical point of view, but also regarding the ecodesign. As this law is not yet implemented, it is not easy to get the needed consumption information from the manufactures for efficiency calculations. Thus, for this work existing devices that one can purchase in Portugal were chosen.

The annual energy needed to heat water for a given household can be obtained from the well-known relationship between heat and temperature change  $\Delta T$  [15]

$$Q_{WH} = mc_p \Delta T \quad (3)$$

where  $m$  corresponds to the mass of water that is heated and  $c_p$  is the specific heat of water which corresponds to  $c_p = 11.62 \times 10^{-4} \frac{kWh}{kg \times ^\circ C}$ . Assuming that the annual average ambient temperature for Portugal is 18°C and that the heated water reach maximum temperature of 50°C (a value higher than 35°C, the defined minimum value for sanitary hot water [15]),  $\Delta T=32^\circ C$  for a tankless system. In a storage system the temperature difference needs to be higher than the assumed as it losses heat while storing the water thus taking  $\Delta T=42^\circ C$ . Independent on the source, the energy that the water heating requires has to be produced. For a smart storage system the calculated value is 641.28 kWh/(year×person) and for the tankless systems it is 488.60 kWh/(year×person). Considered water heaters are combustion devices (such as natural gas, propane and biomass heaters), electrical devices (as water heat pump and resistance water heater) and solar devices (as forced circulation system and thermosyphon). Furthermore, boiler devices are considered for water and space heating.

In order to know when space heating or cooling is required, Lisbon temperature data from the last six years was analyzed [16]. One then can obtain the number of heating or cooling degree days for an average year. However, the energy needs for these services do not just depend on the outside temperature. Building constructions as well as habitant's behaviour influence the demand. Energy needs for space heating  $Q_{SH}$  and space cooling  $Q_{SC}$  are calculated as defined by [15]. The

energy needed to satisfy  $Q_{SH}$  can be calculated using equation (4).

$$Q_{SH} = \frac{(Q_{tr,i} + Q_{ve,i} - Q_{gu,i})}{A_p}, \quad (4)$$

where  $Q_{tr,i}$  is the heat transfer via buildings surroundings,  $Q_{ve,i}$  the heat transfer by ventilation,  $Q_{gu,i}$  the heat earnings due to solar radiation and  $A_p$  the interior pavement area. For a NZEB with 100m<sup>2</sup> and two envelope sites in contact with another building, the calculation gives a value of 174.11kWh/year. The value of space heating depends essentially on the chosen isolation. If the heat transfer coefficient is not that efficient as assumed here, the space heating demand for 100m<sup>2</sup> is about 850kWh/year. This value is consistent with the analysis done by [4]. As space heating devices are considered combustion devices (such as wood furnace, fuel boiler systems and biomass boilers), electrical heaters (as air conditioners, geothermal heat pumps, infrared heaters and resistance heaters) and the thermal solar forced circulation system.

The energy needed for space cooling can be calculated by equation (5)

$$Q_{SC} = \frac{(1 - \eta_v)Q_{g,v}}{A_p}, \quad (5)$$

being  $\eta_v$  as rate of thermal gains and  $Q_{g,v}$  the heat earnings due to solar radiation. Also the space cooling value was confirmed with the study performed by [4]. For a not isolated house, the value for a cooling area of 100m<sup>2</sup> is about 245kWh/year. Considering however a NZEB, this value decreases to 133.86kWh/year. It is considered that space cooling can be done by air conditioners or geothermal heat pumps. Notice that the obtained values are calculated with ideal approaches and may not correspond completely to reality. For other energy services, it is possible to estimate the annual energy consumption directly from manufacture data.

### 2.3 Onsite renewables

To evaluate onsite renewable production, solar thermal systems, photovoltaics and a wind turbine are considered.

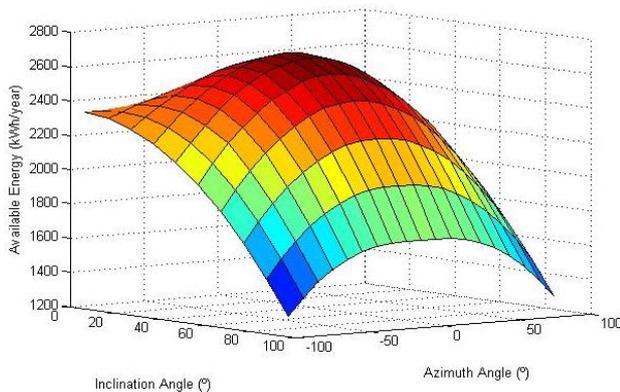


Figure 2: Available energy per square meter in function of different angle inclinations

The available solar energy in a certain region can be estimated by the physical quantity irradiance  $G$ , which gives us the amount of power available per square meter. Global irradiance depends on the position between the Sun and the Earth and therefore is angle dependent. The higher the irradiance, the bigger available energy value will be and the more energy the PV panel can convert. The inclination of the PV panel will affect the value of the captured irradiance and thus it is important to study different panel inclinations. The optimal inclination depends also on the time of the year. In Figure 2 the average annual optimal angle for Lisbon is simulated [17].

For a fixed inclination system the best angle for annual production is 34° and south faced (0° as azimuthally angle). This fixed angle is chosen for solar thermal systems and fixed photovoltaics. For these solar options, the algorithm will optimize the used area, taken available roof area into account. The efficiency  $\eta$  of solar water heaters can be calculated by equation (6).

$$\eta = \eta_0 - k_1 \frac{(T_m - T_a)}{G} - k_2 \frac{(T_m - T_a)^2}{G}, \quad (6)$$

where  $\eta_0$  is optical efficiency, which is the maximum efficiency without considering any heat losses,  $k_1$  and  $k_2$  are the first and second order heat loss coefficients respectively,  $T_m$  is the mean temperature of the collector fluid and  $T_a$  the mean ambient temperature.  $\eta_0$ ,  $k_1$  and  $k_2$  are normally given by the manufacture [18].  $T_a$  and  $G$  can be estimated by [17] which gives the annual average values for Lisbon of  $T_a=17.92^\circ\text{C}$  and  $G=467.51\text{Wm}^{-2}$  considering the optimal inclination angle.  $T_m$  is considered 50°C for solar water heating systems [19].

These devices may however not be enough to produce the required heat over the whole year. The EU indicated the rough value of 60% [13] of the water heating needs that can be satisfied with thermal solar systems, which seems imprecise when taking the number of people plus two distinguished technologies of the solar circuit system and thermosyphon into account. In order to estimate how much energy the solar option is able to produce over the year from the total water heating, the produced energy from the solar heater is divided by the households energy needs for this service.

For the PV analysis, it was considered a monocrystalline PV panel with an efficiency of 20% [20]. Notice that the specific technological choice does not influence much the optimization outcome, once the modules are sold for  $\approx 1\text{€}/\text{Wp}$ . Equation (7) will be used to estimate energy production from the panel.

$$E = \eta_{inv} H_{aver} \eta^r A \quad (7)$$

where  $\eta_{inv}$  is assumed to be 80%,  $H_{aver}$  is the average annual exposure for the surface of 34°,  $\eta^r$  is the efficiency of the panel at STC and  $A$  the panel area [21]. From [17] it is possible to calculate that the average available annual energy in Lisbon at a 34° surface is 2032kWh/m<sup>2</sup>. Considering the systems losses and the chosen solar panel, the actual usable energy is 227kWh/m<sup>2</sup>. The use of PV energy production has also unavoidable storage limitations. The option to

implement battery storage influences the percentage of produced energy that can actually be used inside the household. As the battery has a given capacity, when the battery is full, the additional energy or is not taken advantage of or is sold to the grid. Grid selling can be cost-beneficial for the owner of renewable onsite production, as it can help to shorten the payback period. However, the program will not consider grid selling as to these do not directly influence LCC or LCOT. Additionally, the decline of grid selling prices over the past years suggests that this option is not permanent. Without the storage, most energy is available during the day. As people are working during daytime, the produced energy could be used for the refrigerators or sell to the grid.

In order to calculate the value of available energy for a household per square meter in each case, the degree of self-sufficiency  $d$  is calculated. This degree gives us the value of the share of the load consumption that is supplied by the PV battery system – equation (8).

$$d = \frac{E_{DU} + E_{BD}}{E_{demand}}, \quad (8)$$

where  $E_{demand}$  is the energy demand of the household,  $E_{DU}$  is the energy that is used directly from the PV panel and  $E_{BD}$  is the energy discharged from the battery [22]. The authors of [22] analysed this parameter and was able to obtain Figure 3. Battery capacity values and PV system size are normalized with energy demand values. The values of self sufficiency of this analysis are used for the program. Notice that with no battery storage,  $d$  reaches around 30%. Another observation is that PV systems for the residential area are normally sized around 1kWh/MWh. For these systems, it does not make much sense to install a battery capacity higher than 1.5kWh/MWh as  $d$  will not increase higher than 56%.

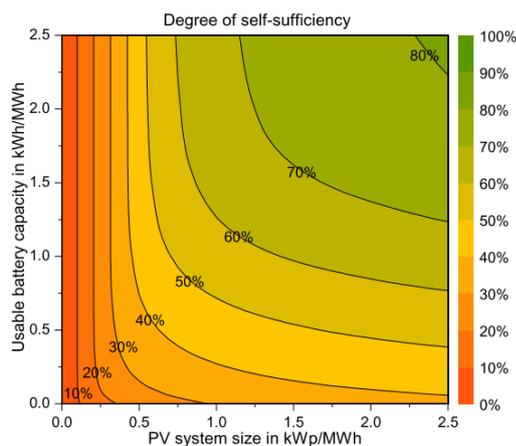


Figure 3: Degree of self sufficiency in function of normalized battery capacity and PV size [22]

In order to know how much energy can be obtained out of wind energy, equation (9) is essential.

$$P_{avail} = \frac{1}{2} \rho A U^3 \quad (9)$$

where  $P_{avail}$  is the available power,  $\rho$  the air density,  $A$  the swept area and  $U$  the wind speed. The wind speed influences the available power most. One model to estimate the wind speed probability is the Weibull distribution. Defining the reference hub height as 10m, the shape parameter as 1.6, and  $z_0$  depending on the site it is possible to obtain the probability for certain wind speed values (see Figure 4).

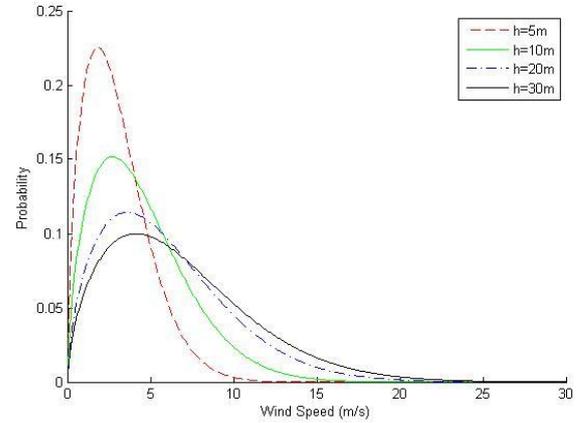


Figure 4: Probability of wind speeds in given heights with roughness length  $z_0=1.2m$

Height has the biggest influence of the available energy for wind production. For smaller heights, the average wind speed is lower than for higher heights. The distribution also shows that with higher heights, the wind speeds are more disperse. This is favorable as the wind turbines that normally starts producing energy from  $3ms^{-1}$ , are able to capture more wind energy. The roughness parameter has a smaller influence, however it will be taken into account in which landscape the house situates. For wind energy production it is chosen a wind turbine available to purchase in Portugal. The three blade model seems adequate and has medium investment costs. From the wind turbines power curve and annual energy production (AEP), it is possible to fit a polynomial curve in order to obtain produced energy in function of height - Figure 5.

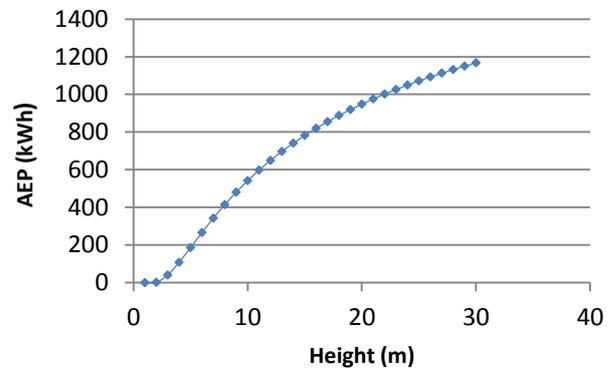


Figure 5: Fit of the annual energy production in function of different heights with roughness length  $z_0=1.2m$

The cost has to be given in function of height, too. It is possible to divide the costs of the wind turbine into two parts. The first part is the cost of the wind turbine itself

and the second part the costs of the tower was assumed that the wind turbine has a lifetime of 20 years; however the tower (considered to be made out of steel) is an onetime investment [23] [24]. As wind production is quite low and the wind speed is taken in average, it will be assumed that all produced energy can be consumed in the household.

## 2.4 Optimization approach

Linear programming is an algorithm method to solve linear optimization problems with the following form:

$$\begin{array}{ll} \text{Optimize} & f(x) \\ \text{Subject to} & Ax \leq b \\ \text{and} & lb \leq x \leq ub \end{array}$$

where  $f(x)$  is the objective function,  $Ax \leq b$  the constraints expressed in matrix form and  $lb \leq x \leq ub$  the bound within the variable  $x$  is valid. Linear Programming has the big disadvantage to only optimize one objective function. However, this optimization method will help this work to decrease the number of variables present in the GA problem. Models in which first the number of GA variables is reduced and then its optimization is performed were already used by [11]. The MATLAB inbuilt command used to perform LP is `linprog()`. From the three different solving methods which are offered by this function the simplex method was used.

As described in the introduction, GA repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects randomly individuals from the current population (parents) and uses their genome to produce a next generation (children). The production of a new child includes crossover and mutation rules. Over various generations, the population evolves towards an optimal solution. The chosen technologies for this optimization method are the most succeeded from LP analysis. For this work, the initial population contains 100 individuals with each 22 chromosomes. Thus an individual (solution)  $n$  has 22 technologies which can provide the energy demand. Each chromosome presents the choice of a technology option. In order to limit the random initialization, each chromosome has to be within the established limits for its technology. During the crossover and mutation procedure, the algorithm always verifies that the chromosomes do not leave their limits. In *Figure 6* a schematic of the process is presented. Note that because the GA performs its search randomly, the optimum solutions in different runs may not be identical.

To run this algorithm in MATLAB, the inbuilt function `gamultiobj()` was used. The function searches for non-inferior solutions and presents them directly. These solutions are basically frontier solutions in which the improvement of one objective function is the degradation of the other. Such a frontier constituted out of non-inferior solutions is called Pareto front [25]. The function itself gives the designer the possibility to write its own selection, crossover and mutation function and

to determine several other parameters such as step sizes or initial populations [25].

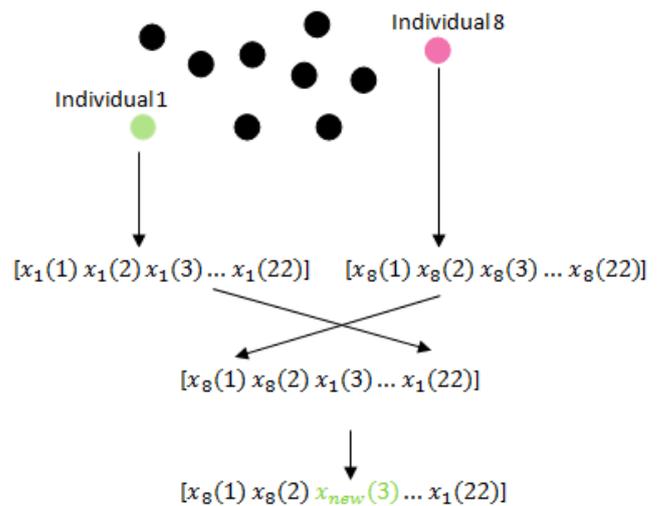


Figure 6: Schematic of the GA process: selection from the population, crossover and eventual mutation

As GA has some problems in accepting rigid linear constraints, the penalty function approach was used. The purpose of this method is to transform the constrained optimization problem into an equivalent unconstrained one, which is more adaptive for GA to solve. In this work the penalty functions were manually added. Thus it will be used the approach of the static penalty for additional cost or energy parameters and a dynamical method for satisfying energy demand and available space for solar installations. For each of these constraints it has to be defined a penalty coefficient. Their weights define how strong the fitness function is going to be penalized.

## 3. Results

To show possible results for LP and GA, two scenarios are analyzed. In scenario 1 a two-person apartment is considered - *Table 1* and in scenario 2 a four-person family house - *Table 2*. For GA, it will be considered also a third scenario of two-person private house.

Question	Answer
Number of people	2
Hot water consumption	36L day <sup>-1</sup> person <sup>-1</sup>
Heating preferences	1 room (20m <sup>2</sup> with 2 contact walls)
Cooling preferences	1 room (20m <sup>2</sup> with 2 contact walls)
Lightning	28m <sup>2</sup> in average 4h per day
Kitchen appliances	Only electrical cooker
Washing appliances	Only washing machine
Available rooftop area	5m <sup>2</sup> (no storage)
Wind turbine	1
Water heating demand	1282.6kWh
Space heating demand	52.17kWh
Space cooling demand	29.84kWh

Table 1: Case study scenario 1: a two-person city apartment.

Question	Answer
Number of people	4
Hot water consumption	36L day <sup>-1</sup> person <sup>-1</sup>
Heating preferences	2 rooms (30m <sup>2</sup> and 15m <sup>2</sup> with 2 contact walls)
Cooling preferences	2 rooms (30m <sup>2</sup> and 15m <sup>2</sup> with 2 contact walls)
Lightning	45m <sup>2</sup> in average 5h per day
Kitchen appliances	Dishwasher, cooker and stove
Washing	Washing machine and dryer
Available rooftop area	20m <sup>2</sup> (with storage)
Wind turbine height	1
Water heating demand	2565.1kWh
Space heating demand	112.29kWh
Space cooling demand	59.63kWh

Table 2: Case study scenario 2: a four-headed family house

### 3.1 Linear programming

Difficulties arise in this type of optimization with choosing only one objective function, which is not sufficient for the aim of this work. However, linear programming shows to be very useful in function as a hybrid model, selecting relevant technology choices for the GA. LP is tested for two different objective functions. The first objective function is to minimize energy consumption for a given energy service. The second objective function is to minimize LCOT.

The number of persons does not affect so much the choice of technology, but the needed energy that a chosen technology needs to deliver, which increases the associated fuel costs. The chosen objective function however influences most of the technology choices. While the first objective function chooses the most efficient technologies, the second objective function chooses the options with the lowest cost impact.

The best technologies for water heating were the heat pump, the solar circuit system, the thermosyphon, the biomass boiler and the natural gas boiler or instant heater. The program determines the needed technologies to fulfil a chosen %RE for an energy service. Thus when considering 50% of RE than the program takes 50% of a renewable resource (solar circuit system or thermosyphon) and a 50% non renewable resource (natural gas boiler or instant heater). For 100% of %RE, the program is forced to implement the biomass boiler which in last instant is the backup system for the thermal water heating devices. Minimizing efficiency and LCOT for scenario 2 (see Figure 7) it is possible to see that the LCOT analysis requires less annual costs. However, when approximating net zero, the annual costs are for both objective functions similar as there are fewer decision devices. It is also possible to say that the annual costs depend strongly on the investment costs of chosen technologies and that fewer technologies for the same energy service are advantageous. For scenario 2, the thermal water heating systems are at their maximum capacity at every %RE value while for scenario

1 just from 80% of %RE on these systems are required fully. The heat pump and the natural gas heater are implemented at lower %RE values. Annual costs for a four person family house are, as expected, much higher than for a two person apartment. Also is it interesting to notice that the program for scenario 1 suggests mostly two technologies, while for four persons three technologies are suggested.

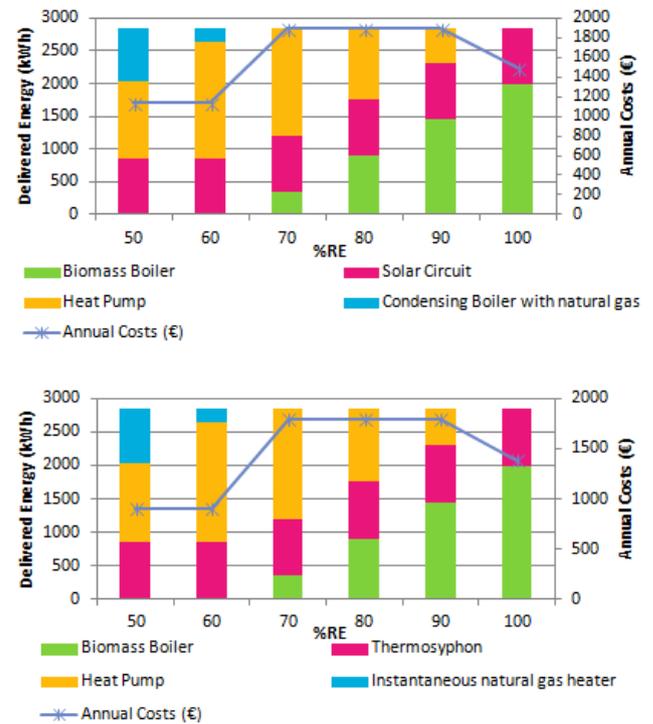


Figure 7: Scenario2: Chosen Technologies for water heating and their associated annual costs, minimizing energy consumption (top graph) and minimizing LCOT (bottom graph)

The space heating technology options are more sensitive to the two different objective function approaches than water heating. It is not only the technologies that vary more between them, but also the annual costs. When optimizing the efficiencies of space heating devices, the biomass boiler and solar circuit systems are the chosen technologies to reach net zero. Biomass boilers as well as solar circuit systems are expensive devices due to their high investment costs. When optimizing LCOT, the program suggests instead of the biomass boiler the wood furnace, a relatively cheap option in investment and fuel cost (see Figure 8 for results of scenario 1). The same conclusions are obtained with scenario 2.

Space cooling has fewer decision devices as water and space heating. Its maximum percentage of renewable supply is given by the renewables present in the grid with a value of 51.94%. The LCOT analysis prefers the horizontal geothermal heat pump once it lowers the investment budget. This option may not be possible for all sites, especially in the city. It could however be an option for a block of apartments (district heating and cooling). The most effective option is the vertical installed system of the geothermal heat pump. This option however is also the most expensive. Space cooling has fewer decision devices as water and space heating. Its maximum percentage of renewable

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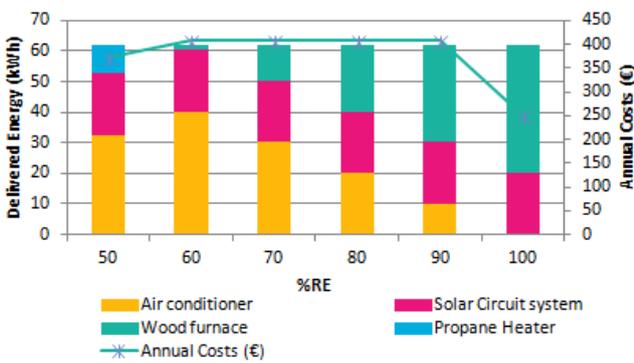
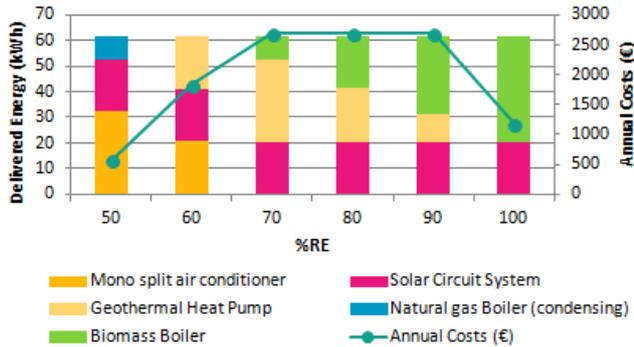


Figure 8: Scenario1: Chosen Technologies for space heating and their associated annual costs, minimizing energy consumption (top graph) and minimizing LCOT (bottom graph)

### 3.2 Genetic Algorithm

To evaluate an obtained Pareto front from the GA optimization depends on the decision maker. There are no favorable solutions in the front as they are all equally optimal. To find most adequate solutions, most of decision makers use the similarity of elements in the non-dominated set and groups these elements. In this work, the Pareto front will be divided into clusters or regions, which have similar technological solutions. The representative solutions of these groups are analyzed, as the objective function values include technologies that are ultimately not used, altering the real value of outside energy and cost. Adequate penalty weights were found and it is possible to verify that diversity stays high as the algorithm always try to find other penalty values. Analyzing the Pareto front from scenario 1 with the LCOT analysis (see Figure 9), the highest percentage of renewable energies present in the total consumption does not vary much to the LCC analysis and assumes a value of 72%. Also the chosen technologies are in general the same. For region A, the wood furnace is considered for space heating, which increases the %RE for this region. All roof area was used for solar thermal

circuit systems. In region B, the value of %RE maintains, however, the wood furnace is substituted with an electrical oil heater and 2m<sup>2</sup> of the roof area is for PV.

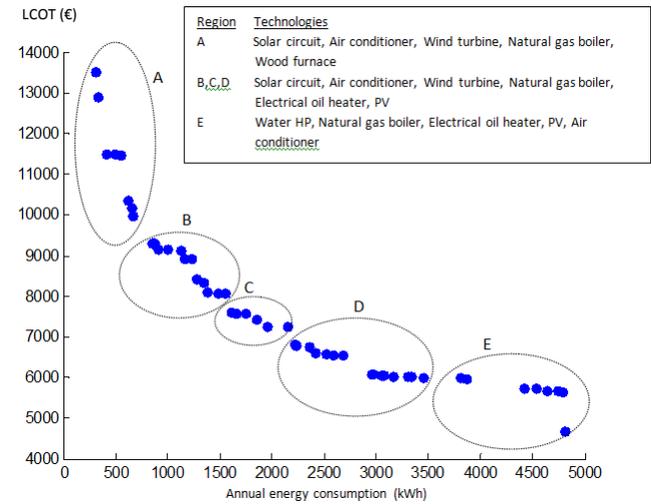


Figure 9: Obtained Pareto front from a two person apartment with LCOT analysis

Regions B, C and D use the same technologies; however the delivered energy from each technology differs. Thus region C can present 63% of %RE and region D 59%. The region with the lowest %RE of 34% is E. This region does not consider any solar thermal options and uses the water heat pump and natural gas boiler for water heating. The biggest difference is certainly in the energy onsite supply. After knowing which technologies are considered, it is recalculated their LCOT. Notice that technologies such as the electrical heater and the air conditioner with little energy delivery have higher LCOT values. Region C with 63% will be considered the best trade-off between the objective functions, as it is situated in the central region of the Pareto front. The distribution of the technologies in the whole household consumption in this case can be seen in Fehler!

Verweisquelle konnte nicht gefunden werden..

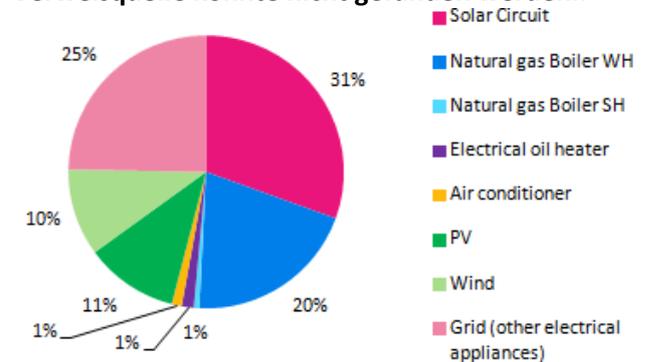


Figure 10: Provided energy by sources for C with 63% of the household's energy coming from renewables

The maximum achievable value of %RE for the LCC analysis with scenario 2 is 77% (region A – see Figure 11). In region A solar thermal option, biomass, PV and wind are considered. The available rooftop area is divided into 9m<sup>2</sup> of PV and 11m<sup>2</sup> for solar thermal systems. The optimal hub height was estimated

between 7 and 8m. Region B presents 74% of renewables, with the big difference of using the air conditioner instead of the wood furnace and lowering the wind turbine hub height to 6m. The chosen technologies are identical in region B and C, however in region C less space from the rooftop area is used. This process decreases the LCC and also %RE to 71%.

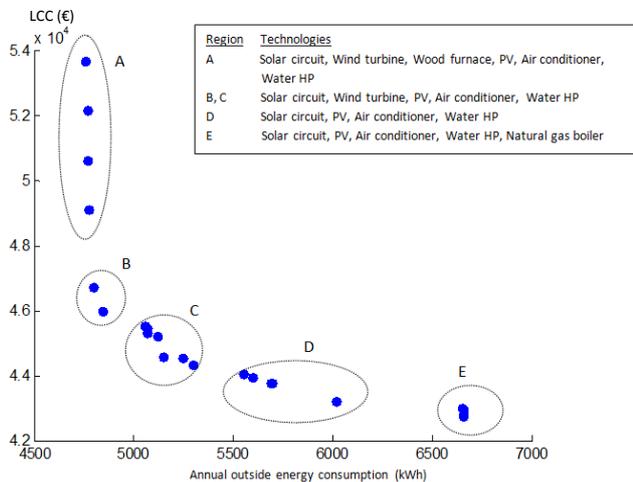


Figure 11: Obtained Pareto front from four person house with LCC analysis

In region D, the rooftop area is only used with 8m<sup>2</sup> for solar thermal and PV systems. The wind turbine is not considered in this region anymore. The %RE for this region is 64%. In the last region E the %RE drops to 57%. Less renewable technologies are considered and option such as the natural gas boiler systems substitute them.

In Figure 12 one can see the annual LCC for each region. It is clearer than in scenario 1 that the higher the %RE, the higher the LCC costs. Region C is considered the best trade-off solution (see Figure 13). It is possible to verify that most of the energy is for water heating.

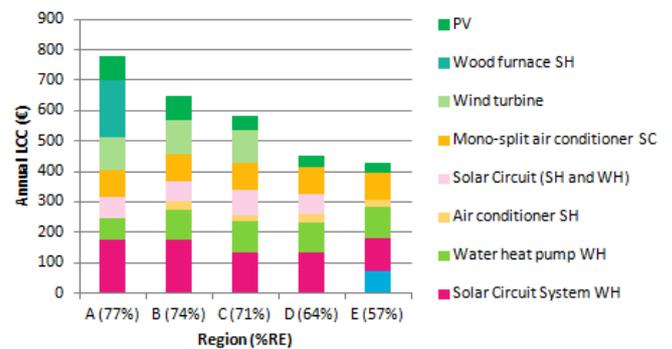


Figure 12: Annual LCC and chosen technologies per region for scenario 2

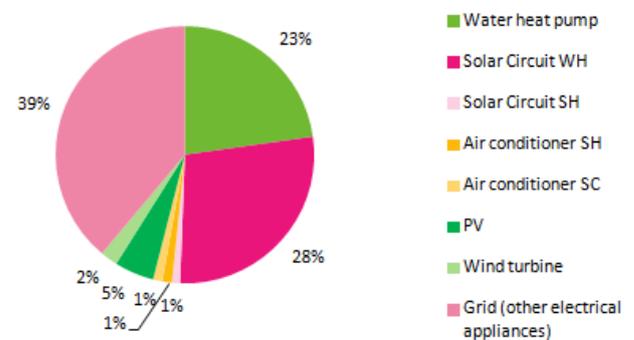


Figure 13: Provided energy by sources for C with 71% of the household's energy coming from renewables

Nº of persons	House type	Cost analysis	Annual costs (€)	Highest %RE	Considered %RE	Considered technologies
2	Apartment	LCC	400.81	69%	59%	Solar circuit, Air conditioner, Natural gas boiler, Electrical oil heater, PV and Wind turbine
		LCOT	839.99	73%	63%	Solar circuit, Geothermal heat pump, Biomass boiler, Wood furnace, PV and Wind turbine
4	House with garden	LCC	535.77	77%	71%	Solar circuit, Air conditioner, Water heat pump, PV and Wind turbine
		LCOT	3947.03	86%	83%	Solar circuit, Geothermal heat pump, Biomass boiler, Wood furnace, PV and Wind turbine
2	House with garden	LCC	779.09	89%	89%	Solar circuit, Air conditioner, PV and Wind turbine
		LCOT	1901.52	91%	91%	Solar circuit, Air conditioner and Wind turbine

Table 3: Comparison between the analysis

#### 4. Conclusions

From Table 3 it is possible to suggest values for renewables present in the energy consumption of a nearly NZEBs in Portugal. This value depends on the house type and on the number of person present in the household. Furthermore, the value can be influenced by the behavioural aspects of energy demand. This work suggests the value of 60-65% of %RE for smaller

installations such as apartments and town houses. For houses with more available space for onsite renewables, the suggested value ranges from 75-80%. Dividing houses into classes and determine the mandatory %RE value seems the right juridical approach.

Continuing implementing renewables for the grid system is also a right approach. For this, electrical appliances in

the household should be chosen over gas systems. It has been showed that fewer technologies for the same energy service are cost favourable. Additionally, solar thermal systems should be a must in Portugal once they were included in every simulated case. Solar PV systems compensate when more space is available. Water heating was the energy service with the biggest influence in energy consumption. Space heating and cooling are able to decrease taken the right isolation for the NZEB. When calculating annual costs, the LCOT analysis presents higher values than the LCC analysis.

However, the LCOT technologies provide always a higher value of %RE and include also expensive option such as the geothermal heat pump. LCOT and LCC are both cost comparison method, which give different results. It depends on the required optimization approach in order to choose. While LCC has the advantage of obtaining real cost values, LCOT is able to compare the technologies directly to each other and to eliminate options in case of doubt. The practical implementation of certain case studies performed in this work may not be as simple as shown as it depends from case to case.

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