Promotion of Energy Efficiency Measures in Academic Dormitories

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Abstract

The main objective of this study would be to contribute to the future installation of an alternative system to the gas boilers, producing domestic hot water, installed at Academia Militar - Portugal (Amadora Quartering). The focus was centred on determining the economic feasibility of each option to be installed in the dormitory, body 3, of the Military Academy building. The building revealed a total capacity of 78 students, using an average of 75 litres of water, in daily baths, for each one. The annual energy requirements for the preparation of Domestic Hot Water (DHW) were calculated in accordance with the Regulation on Energy Performance of Housing Buildings (REH) and by using the *Polysun* software, obtaining a value of 40.25 MWh/year for the preparation of DHW. Using the software *Polysun*, four alternative systems were designed, namely a Vertical Ground-Source Heat Pump system (VGSHP) with the aid of a Solar Photovoltaic system, a Solar Thermal Collector system (STC) with the aid of a thermal resistance , another STC with the help of VGSHP and, finally, a STC system with an air-water Heat Pump. All these options were compared, in energy and financial terms, with the base system already installed in the case study building. The energy balance revealed large savings in terms of fuel used, leading to a large reduction in CO2 emissions. The financial analysis, considered for a 25-year project, showed great savings for the alternatives at the end of the period. The STC system with air-water heat pump showed an accumulated expense lower than the initial investment, with a value of 62119 €, around 2663 € less.

Keywords: Solar thermal, heat pump, solar photovoltaic, energy balance, financial statement.

1. Introduction

For a long time, activities related to the efficient production and distribution of Domestic Hot Water (DHW) were neglected, and sidelined, due to the insignificant share of total energy used in buildings. More recently, DHW has emerged as a major contributor to a large part of a building's total energy use. Its share continues to increase while a decrease is observed in other segments. In 2013, the useful energy consumed for space heating reached a value in Europe of 2326 TWh, and for DHW production it was equivalent to 19% of the energy needs [3]. With the improvement in the area of thermal insulation for buildings, as required by the European Directive 2010/31/EC, the significance of the thermal energy consumed in DHW continued to increase reaching values in the order of 50% in new and well insulated buildings [1].

This project uses the Amadora Military Barracks as a case study, where several DHW systems will be dimensioned for one of the bodies, in this case body 3 of the building. Four designs will be performed with different types of equipment, always focused on the production and distribution of energy from renewable energy sources. The energy, economical and ecological aspects will be analysed for each alternative hypothesis to the implemented system. However, the main factor will be the water consumption for each occupant, because it is the starting point for a correct sizing of the systems to be implemented.

2. Case Study Framework

The building chosen for this case study was considered due to its proximity with the "boiler house", enabling the use of part of the DHW distribution system, namely some tanks and exchangers. The chosen building can be seen in Figures 1.

It consists of three floors, ground floor corresponding to floor 0, first floor as floor 1 and second floor as floor 2, where it has a total capacity of 78 students. There are four bathrooms for a total of 7 showers per floor, giving a total of 21 for the whole building.

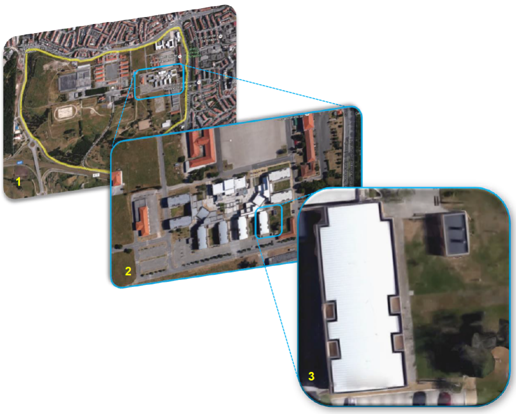

Figure 1: Building chosen for the case study, represented in the 3rd image [6].

2.1. Local Climate

According to the climatic classification of Köppen [14] the region of the Municipality of Amadora fits in the temperate Mediterranean climate, presenting the same characteristics as the Iberian Peninsula [14, 8].

The data for the Amadora region were provided by the *Polysun* program, which acquires and examines numbers coming from the *Meteorm* software [19]. It has a warm period, which lasts approximately 4 months, starting in late May and ending in late September, with highs close to 30 ℃and lows around 16 ℃. In contrast with the aforementioned time interval, there is a colder period where it is easily observed that January and December are the months with the greatest drop in temperature, registering a minimum of around 5 ℃[19].

Moving on to another point the direct normal irradiation throughout the year for the site in question it has minimums around 50 W/m^2 and maximums above 1000 W/m^2, with a smaller oscillation in the hot period and, contrarily, a greater energy oscillation in the cold period.

2.2. Local Geology

The Military Academy, Quartering, is located in the municipality of Amadora.From a geomorphological point of view, it is a flattened area, defined by a platform with gentle slopes, altitudes of 125 meters at the Western limit of the Military Academy - Amadora Barracks, and 136 meters in the Eastern zone.

The region to be studied is positioned on sheets number 34-C (Cascais) and 34-D (Lisbon) of the Geological Map of Portugal at a scale of 1:50000 [13, 17]. From a geological point of view, the region to be studied is called the Lisbon Volcanic Complex (LVC), installed between Upper Cretaceous and Holocene [20, 21, 16, 17]. The LVC occupies an area of about 200km^2 between Lisbon and Sintra. The complex lies both on the Holocene marlitic limestones and on the Upper Cretaceous reef limestones and covered by the Paleogene conglomeratic layers of the "Benfica Complex" formation [20, 21, 16, 17]. Table 2.2 demonstrates the characteristics of the main thermal properties of the various rock types present in the region [2].

Table 1: Thermal properties, at 25 ℃, of the characteristic rocks of the Amadora region [2]..

Rock Type	Thermal Conductivity (k)$[W.m^{-1}K^{-1}]$			Specific Heat (Cp)$[J.kg^{-1}$	Rock Density (ρ)$[kg.m^{-3}]$	Thermal Diffusivity (α)$[m^2.s^{-1}]$	
	Minimum	Average	Maximum			Minimum	Maximum
Basalt	2,0	2,2	2,4	712 - 879	2880	$0,97 \times 10^{-6}$	$1,17 \times 10^{-6}$
Limestone	1,4	2,4	3,4	920	2400	$0,64 \times 10^{-6}$	$1,54 \times 10^{-6}$
Stoneware	2,0	2,5	3,0	1005	2560	$0,77 \times 10^{-6}$	$1,17 \times 10^{-6}$

3. Domestic Hot Water Systems

In [15], and supported by several studies, it is stated that a large part of the energy lost in an DHW system occurs during distribution and circulation, in certain cases it exceeds the energy consumed by the output points. Another point associated with energy loss in DHW is at the level of storage in the tank. Compared to the losses in circulation, the energy lost at this level represents, most of the time, a small part of the total energy used in the system. [15] highlights values between 2 and 36% based on the literature, where the variation is dependent on tank size, insulation and water circuit.

In terms of DHW storage in tanks, another point to consider is directly related to their dimensions. On the one hand, an oversized tank will lead to greater thermal losses due to a larger heat exhaust surface, as well as a higher associated cost and, finally, there may be sedimentation of old water because there is not total consumption. In the case of an undersized tank, there will not be enough capacity for the needs of the consumers, causing complete tank discharges, leading to a decrease in the efficiency of the system as a whole, and in the case of being associated with solar collectors, it causes a decrease in the solar fraction.

Continuing to highlight the key points for greater efficiency of a DHW production and distribution system, according to [15] and his review of the state of the art, regarding distribution, it is shown that thermal losses vary depending on the building typology. That is, the losses are directly proportional to the distance between the production system and the outlets (faucets, showers, etc.). Also directly related is the fact that the lower the consumption, the longer the water retention time in the distribution system, which will also contribute to an increase in losses. As a countermeasure, [15] describes that careful planning needs to be done with regard to outlets, improving, or if not available, using insulation in the distribution piping. [15] highlighted a maximum reduction of 18% in the distribution system when using greater thickness with values of around 30-50% more. Regarding the material used in the piping, it was revealed that it has little influence on the thermal losses, the variation being less than 8%.

In [9] it is concluded that, if applicable, decreasing water flow in the distribution system, accompanied by a decrease in storage capacity, will bring an annual reduction of between 15% and 25% in energy needs and increase the overall efficiency of the system. This method could be applied by changing the shower heads so that the maximum flow rate is reduced. By itself, it would allow a reduction in the storage tank capacity and reduction of the total power in the production systems, this would imply lower thermal losses and lower initial investment.

An important aspect to take into account is the amount of water consumed by each person. In [5], a study conducted in a dormitory in Belgrade, the recommended daily value would be, according to the literature review, 49.7 liters for males and 46.6 liters for females. But in the case study, a value of 40 liters would be applied regardless of gender. In [12] and its literature review, the values to be applied are between 30 and 50 liters per day, per occupant, regarding studies conducted in the UK and Ireland. In the case of [10], based on behavioral analysis, experience in the military academy and estimates through water bills, a value of 192 liters per student is reached, as these students take two showers per day with a duration of 8 minutes and a shower flow rate of 12 L/min. In the case of [7], a lower value is already demonstrated, with the only difference being in the flow rate of the showers that was decreased to 10 L/min, leading to a value of 160 Liters per student. However, it is still a very high value when compared to other studies related to DHW consumption profiles.

3.1. Annual heat energy requirements for domestic hot water (Q_{DHW})

The use of the equation 1 allowed to determine the amount of liters spent per student.

$$L_{student} = C \times B \times Min \tag{1}$$

Where "C" is related to Shower flow rate [L/min], "B" to baths per day and "Min" to minutes spent in each bath.

Replacing "C" by the value of 10 liters per minute, the term "B" by 1.5 and using an average value of 5 minutes per bath, a value of 75 litres per student is obtained.

To make the comparison with [6] and [11], the equation 2a is also used, where the values were obtained according to Order (Extract) No. 15793-I/2013 of 3 December, under and for the purposes of Decrete-Law No. 118/2013 of August 20, which is used to determine the nominal needs of useful energy for DHW production, where the standard value for litres spent per person is 40. Thus, the equations 2a and 2b allow obtaining the average daily DHW consumption as in the two studies referred to at the beginning of the paragraph.

$$M_{AQS} = 40 \times n \times f_{eh} \tag{2a}$$

$$M_{AQS} = L_{student} \times n \times f_{eh} \tag{2b}$$

In equations 2a and 2b, the term "n" represents the number of occupants of the building, which in this case will be 78 students. In the case of "f_{eh}", this is the water efficiency factor, applicable to showers, or shower systems, with water efficiency certification and labeling under the responsibility of an independent entity, recognized by the building installation sector. Where, in the case of showers or shower systems with label A or higher, it has a value of 0.90, and in other cases, and applied to this, it takes the value equal to 1.

In this case, the equation 2b was used to calculate the nominal useful energy requirements for DHW production. The only difference will be the value of "$L_{students}$", where the eq.2a uses a value defined by 40 L/student and, in this case, it will be a value of 75 L/student, so that there is a safety in performing the sizing. It should be noted that there is a considerable difference in the average daily amount of DHW, where the equation 2a, equals a value of 3120 liters, compared to the 5850 calculated for this case.

After the daily average DHW calculation, the useful thermal energy required in annual terms (MWh/year) is evaluated. Through the equation 3 it is possible to obtain the referred values according to the Order (Extract) No. 15793-I/2013 of December 3.

$$Q_{AQS} = \frac{M_{AQS} \times 4187 \times \Delta T \times n_d}{3600 \times 10^6} \tag{3}$$

Where ΔT epresents the temperature rise required for DHW preparation and n_d represents the number of days of DHW consumption during the year.

Here, M_{AQS} will have the value referred to in the previous paragraphs, the 5850 liters. The term "ΔT" will have a value equal to 23.2 ℃instead of the 35 ℃predefined in the Dispatch referred to above, where the reason for this change was due to the outlet temperature, defined in the software *Polysun*, being 40 ℃. As for the term "n_d", it will also have a different value than supposed because, after discussion with Professors and users, 255 days of use were accounted for, due to vacations, holidays and weekend absences, instead of 365 days in the year.

3.2. Hypothesis A

The hypothesis A tests the configuration and arrangement already installed, consisting of two gas boilers, two storage tanks and a forced circulation system. The boilers are Roca brand, have a nominal power of 380 kW, a maximum temperature of 95 °Cand were installed in the year 2003. The production considered for the boiler is 68%, since it is more than 10 years old. The yield of this element is something that will not be possible to simulate in the program, since it does not allow us to configure this aspect, only to choose models from a wide list already predefined. As for the storage tanks, little information was obtained regarding these, estimating a total of 5000 litres for each.

For such a simulation, and for it to be configured with maximum accuracy, the software *Polysun* requires input data of prior knowledge. Of which are inserted the consumption absences, consumption profiles, anual demand of DHW [m^3], water temperature at outlets, lengths and diameters of the piping of the distribution system and location of the installation.

These points, referred above, serve as a basis for the next hypotheses presented, being that the values for these parameters remain unchanged throughout the simulation of the alternatives to the base system (Hypothesis A).

Regarding absences, they are accounted through the days in which students are not present in the campus, arriving at an estimated value of 110 days in which students don't make use of the facilities.

Considering the consumption profile, it was consulted among students, teachers who teach at the Military Academy and advisors of this project, that the most approximate value would be 40% at 7 am, 40% at 8 am, again 40% at 7 pm and the rest at 8 pm.

As for the annual consumption, in m^3, it will be a value of approximately 1790 m^3 with a safety factor of 20%.

Concluding that it will not be necessary higher values, it was defined a temperature in the exit points in the order of 40 °C.

At the beginning of the subchapter the steps for obtaining the approximate values for the amount of piping used in the distribution system are described, using a total value of 270 meters. As for their diameters, its used a value of 100 mm and 25 mm, for outlet and return, respectively. As for the insulation, Armaflex was chosen with a thickness of 19 mm, for Hypothesis A, and a thermal conductivity of 0.04 $W/m.K$. Regarding the diameter of the insulation for the alternative hypotheses (B, C, D and E), it is increased from 19 millimetres to 28 millimetres of insulation thickness in the distribution system.

As for Figure 2, it represents the base scheme of the already installed system.

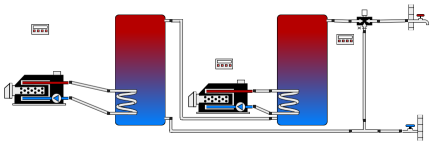

Figure 2: Hypothesis A - Representation of the system already implemented with gas boilers.

Demonstrated by the Figure Fig. 4.4, the energy flow diagram reveals, with 99.7% accuracy in relation to the simulated data, a fuel consumption of 64.6 MWh, of which 42.0 MWh were used for DHW production, 6.5 MWh of thermal losses to the environment and, approximately, 16.3 MWh of thermal losses to the inside of buildings.

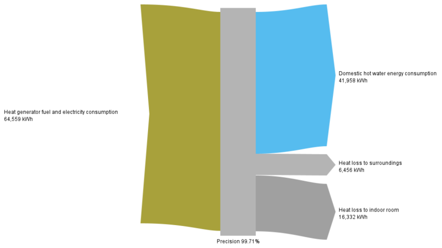

Figure 3: Energy Flow Diagram for Hypothesis A (Annual Balance).

3.3. Hypotheses B

The hypothesis B is composed of a Vertical Geothermal Heat Pump main system (ecoGEO model 5-22), with COP equal to 4.9, EER of 5 and with the aid of a photovoltaic system to cover part of the electricity consumption. The soil conditions are configured as presented in subchapter 2.2, in table 2.2. The exchanger follows the same parameters presented in [6], with a minimum separation of 6.1 meters between vertical holes, high density polyethylene piping, in a "U" shape, with a nominal diameter of 32 millimeters, but with a hole length of 100 meters.

62 photovoltaic modules were used, with 300 W each, to be able to cover the electrical consumption on the part of the total system installed, which makes up an area of the buildings roof of 119 m^2. With a loss factor of 2%, south orientation and with a 55 degree inclination angle, together with inverters with a maximum efficiency of 98%.

Figure 4 represents the schematic of the VGSHP with the aid of the photovoltaic system.

Figure 5 represents the energy flow diagram for the hypothesis considered in this sub-chapter, with an accuracy of approximately 99.6%.

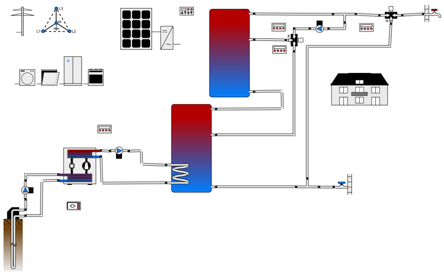

Figure 4: Hypothesis B - Vertical Ground-Source Heat Pump System with Solar Photovoltaic as a complementary system.

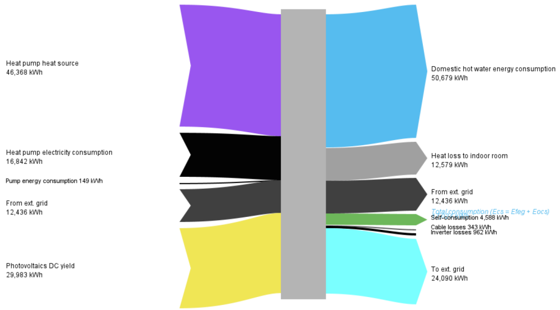

Figure 5: Energy Flow Diagram for Hypothesis B (Annual Balance).

It should be noted the 46.4 MWh in heat from the ground, consumed by GSHP, transformed into 50.8 MWh of energy for DHW consumption, the 16.8 MWh of electricity consumed by the pump and 12.4 MWh of electricity from the outdoor network. Another highlight is the decrease in heat losses to the inside of buildings, going from 16.3 MWh, presented in Fig. 3, to 12.6 MWh only by the increase in thickness by 50%. This was about 23% in heat loss reduction, being higher than the 18% revealed in [15].

Although not evidenced in Figure 5, the use of 62 photovoltaic modules for this system led to a positive annual balance. That is, it was guaranteed that every month the balance of electricity consumed would be negative, that there would be a surplus of energy that would be injected into the grid if there is a possibility.

3.4. Hypotheses C

This new hypothesis is composed of several flat plate solar thermal collectors as a production system, with the aid of a thermal resistance inserted in one of the storage tanks, to combat the energy deficit.

In [18] it was concluded that, for the region of Spain, the ratio between the volume of the storage tanks and the opening area of the collectors (V/A) will be between 0.05 and 0.08 m. Following these calculations, a total opening area of 125 m^2 to 200 m^2 would be presented. Following the rule presented, a value of 60 collectors with an opening area of 125.4 m^2 was arrived at, according to the value referred to for Spain, since the climate is similar to that of Portugal.

The 60 thermal collectors are arranged with south orientation, with a 55 degree inclination angle. Figure 6 represents Hypothesis C, composed of a solar thermal system with electrical resistance as an aid.

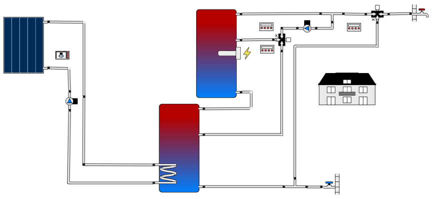

Figure 6: Hypothesis C - Solar Thermal System with electrical resistance as auxiliary system.

As can be seen, Figure 7 demonstrates the energy flow diagram for the Hypothesis C system simulation with respect to an annual balance.

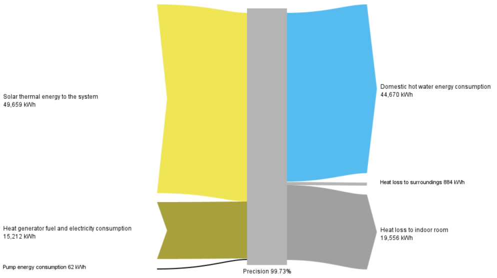

Figure 7: Energy Flow Diagram for Hypothesis C (Annual Balance).

Observing the Figure 7, one can highlight the 49.7 MWh of solar energy inserted in the system, followed by 15.2 MWh of aid by the electric resistance in the boiler and, finally, in the section of the inputs to the system, 62 kWh by the electric consumption of the circulation pumps. Of the 64.8 MWh produced, 44.7 MWh were used for DHW, 19.6 MWh in thermal losses inside buildings and 884 kWh in losses, also thermal, to the environment.

An increase in the thermal losses when compared with the other previous proposed systems is to be noted. This was caused by the larger amount of tubes for water circulation, since the solar thermal system would have to be mounted on the roof of the main building.

3.5. Hypotheses D

In this system 20 flat plate thermal collectors were dimensioned, about half of the previous hypothesis.

They are configured with the same 55 degrees of inclination and oriented south. As for the VGSHP, the heat exchanger has the same characteristics as the previous ones, with the power and model of the heat pump being the only difference to the other systems. Here, the ecoGEO 1-9 model is used with COP of 3.9, EER of 5.2 and power range between 1 and 9 kW. Fig. 8 represents the scheme of Hypothesis D, represented by a solar thermal system with the aid of a GSHP.

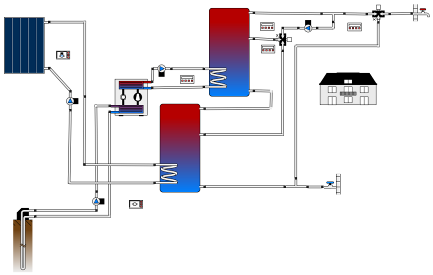

Figure 8: Hypothesis D - Solar Thermal System with Ground Source Heat Pump as auxiliary system.

Figure 9 represents the energy flow diagram for Hypothesis D relative to an annual balance, taking into account all the inputs and outputs of the system in question.

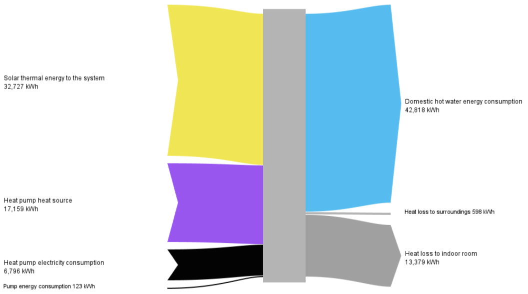

Figure 9: Energy Flow Diagram for Hypothesis D (Annual Balance)

The system produced a total of 32.7 MWh of solar thermal energy, 17.2 MWh of thermal energy from the auxiliary component (VGSHP). Simultaneously, there was an electrical energy consumption of 6.8 MWh by the heat pump and 123 kWh by the circulation pumps. In the case of energy consumption for DHW, it resulted in a total of 42.8 MWh, together with, approximately, 14 MWh of total thermal losses. It should be noted that all the values presented in these diagrams are relative to one year of simulation by the software used in this case study.

3.6. Hypotheses E

The main system is composed by 20 flat plate thermal collectors, with a total area of 41,5 m^2, facing south and with a 55 degrees inclination angle. Regarding the auxiliary system, the model used in this system presents a COP of 4,82 and a maximum power of 11,4 kW, being an air-water system.

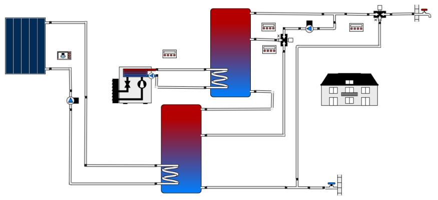

Figure 10: Hypothesis E - Air-to-Water Heat Pump System with Solar Thermal as auxiliary system.

The diagram shows the 33.2 MWh produced by the solar system and the 17.8 MWh produced by the heat pump. There was also an electrical energy consumption, on the part of the heat pump, of around 6.5 MWh and, on the part of the circulation pumps, of 15 kWh. Regarding the outputs of the diagram, 43.3 MWh were used for DHW. As for the remaining energy, it was divided into 13,5 MWh of thermal losses for building interiors and 597 kWh of losses for the surrounding environment. Fig. 11 represents the energy flow diagram for Hypothesis E, regarding an annual balance.

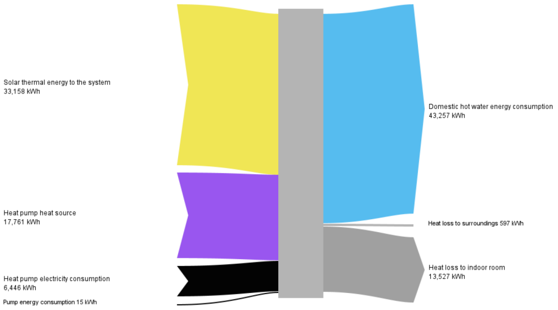

Figure 11: Energy Flow Diagram for Hypothesis E (Annual Balance).

4. Financial Statement

4.1. Operating costs

In order to be able to analyse the economic viability of the suggested hypotheses, it will be necessary to know the total cost of energy spent in the base system. The eq. 4 allows us to calculate the annual energy cost spent in one year, in Euros:

$$\mathit{Annual\ cost\ of\ energy} = \frac{\mathit{Total\ Energy}}{\mathit{COP}} \times \mathit{Energy\ price} \tag{4}$$

Analyzing the energy flow diagram for Hypothesis A, it is observed that approximately 64,6 MWh of fuel (gas) were necessary. This value was according to the simulation made by the program, not including the 68% of yield, because it doesn't allow yield changes according to the age of the equipments.

Regarding the energy prices in Portugal, for the Amadora area. The price of natural gas (Lisboagás) is 0.0422 €/kWh for energy and 0.1938 €/day for the fixed term tariff [4]. As for electricity, the price is 0.0918 €/kWh for energy and 0.0751 €/day for the contracted power [4], for state buildings because they do not pay VAT.

Table 2 presents the costs associated with energy consumption for each technology, taking into account that Hypothesis A consumes natural gas and, for the others, there is an electrical energy consumption by heat pumps and auxiliary resistances. It should be remembered that the value for Hypothesis A is in agreement with the equation 4, demonstrated above, leading to a quite significant increase in simulated consumption.

Table 2: Gas and electricity costs for each system.

Hypotheses	Energy Consumed [kWh]	Energy Cost [€/kWh]	Fixed Term Tariff [€/day]	Contracted Power [€/day]	Total [€]
A	64559	0,0422	0,1938	-	4077,19
B	29427	0,0918	-	0,0751	1764,81
C	15276				1429,74
D	6819				662,58
E	6461				620,53

It is worth highlighting the 4077.19 € for the base system, due to the low yield, the amount of energy spent to obtain the same value for DHW is much higher than expected.

For system B, composed of VGSHP as the main producer, there is an annual saving of 2312.38 €. Part of this expense could was minimized by the sale of excessive energy to the grid (0,04€/kWh), produced by the photovoltaic panels implemented in the system.

In the Hypothesis C, composed entirely by solar collectors assisted by an electric resistance, there is a consumption of 1429,74 € of electricity, obtaining a saving of 2647,45 €.

In the case of the remaining configurations, the saving is already quite significant. The use of heat pumps as auxiliary systems reduces the value of the electricity bill by more than 50%. For Hypothesis D there is a saving of 3414,61 € and in the case of E, there is a saving of 3456,66 €.

4.2. Installation costs

The values used include new systems, in full, to facilitate the comparison between the different hypotheses, also being implemented for the base system. It should be noted that for both the prices presented below and those shown above, VAT (23%) is not included in them, as the case study relates to a government building.

The operation and maintenance costs (O&M) are directly related to the initial investment of the project for each system. In the case of Hypothesis A, it was used a value of 5%, as for the others it was considered 4% for each. Besides these percentages, it is important to highlight the decennial operation costs, where parts of the systems will have to be replaced after 10 years of use.

All the above values are accounted for in the table 3, presented below..

Table 3: Installation costs for each scenario

Hypotheses	Initial Investment [€]	O&M	Ten-year Maintenance Costs [€]
A	41051	2053	9608,06
B	65459	2618	11739
C	71850	2874	26230
D	74828	2993	6973
E	64782	2591	9486

It should be noted that Hypothesis C shows the higher costs with a total of 26230 €. Option D is the one that presents the biggest initial investment, since it is composed by 20 thermal collectors together with a VGSHP, although cheaper than option B, it still has a high value for an auxiliary system. However, in option E, also composed by a heat pump, but this time with an air-water system, the initial investment is the lowest, being 677 € cheaper than system B.

4.3. Economic feasibility analysis

Figure 12 demonstrates the accumulated expenditure for each system, with the difference in annual operating costs (savings) entered as revenue for the alternative configurations (Hypothesis B, C, D and E).

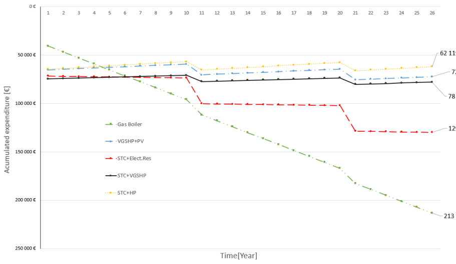

Figure 12: Accumulated expenditure, for each system, over 25 years.

The graphic of Figure 12, demonstrates that Hypothesis A presents the lowest initial costs, being D the highest initial costs of all systems. In the accumulated expenses, after 25 years, system A presents a much higher expense in relation to the alternatives, being 83538 € away from the second most expensive system. On the other hand, system E was the one with the lowest final expense, with a final accumulated expense of 62119 €.

Comparing with Table 3, the Hypothesis E is the only one that presents a final value below the initial investment, presenting a positive balance, in the value of 2663 €, after 25 years.

Observing again the graphic of Figure 12, it is noteworthy that the system B and E becomes more profitable than the present system after 4,5 years, approximately. In the case of the remaining alternatives, it takes 6 years for this event to occur.

5. Results

It is noticeable, according to Figure 12, that the hypotheses using a solar thermal system as main producer present a lower cost in the end, with the exception of system C and its year 10 maintenance cost. Another important aspect is that Hypothesis E can present an accumulated expense, at the end of the studied period, lower than the initial investment. Thus, a positive balance is obtained over the years, being equal to 865 € for each year. The same would happen for Hypothesis D if it weren't for the high cost of replacing the heat pump after 10 years, since it presents a positive cash flow, for the remaining years, of 422 €.

The basic characteristics of the sizing carried out in this case study were the local geology, climate and, mainly, the energy demand at DHW level. Comparative studies, such as [6], [11] and [10], assisted in the choice of the main parameters for dimensioning, through the *Polysun* program. Within the sizing program, all the non-energy producing systems were configured with the same parameters, enabling the best comparison between the presented systems. The control aids also played an important role in the configuration of each system, as they allowed to switch on, or off, devices depending on the temperature of the water in the distribution system and in the storage tanks.

Regarding the distribution system, the insulation was increased by 50% for the alternative systems to the base one. There was a significant reduction in thermal losses to the inside of buildings, where a decrease of 22% occurred in one of the cases. This value is even higher than the 18% referred to as a maximum in [15]. Figure 13 demonstrates the total loss percentages for each system.

Another criterion analysed, and also demonstrated in Figure 13, is the solar fraction for systems C, D and E. Option C shows the highest percentage of SF (Solar Fraction) with a value of 77.5%. The inclination angle of the collectors was one of the points to optimize this criterion. Through trial and error in the simulation, an angle of 55 degrees showed an optimization of energy received for the months of higher energy deficit.

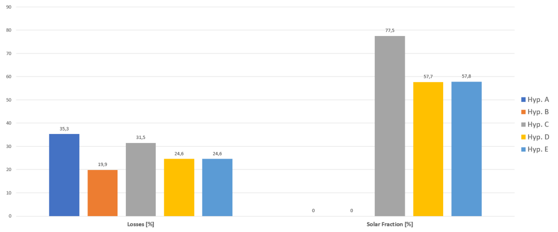

Figure 13: Percentage of Losses and Solar Fraction for each dimensioned system

Being an Academy it was evident that the winter months would be the months of higher occupation and energy consumption, so it would be extremely important that the energy deficit was as small as possible throughout the months of occupation. The *Polysun* program allowed to obtain values about several characteristics of the analysed systems, some of them being presented in Figure 14, where the energy consumption for DHW, the energy deficit and the annual gas and electricity consumption balance are graphically shown. Each hypothesis corresponds to a different colour inserted in the graphic.

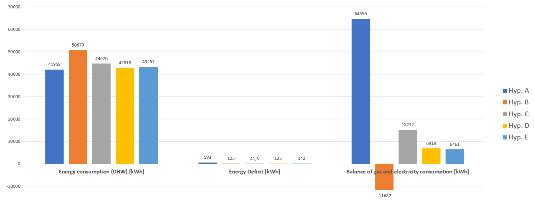

Figure 14: Energy consumption for DHW, energy deficit and balance of gas and electricity consumption for each scenario

In the case of the fuel consumed, a huge difference between the base system and the alternative options can be noted. The Hypothesis B is the only one that presents a negative balance, derived from the excessive annual production by the photovoltaic panels. System C presents the highest consumption of all the alternatives, while the high energy efficiency coming from the heat pumps, in options D and E, reflects the low consumption of electricity by the auxiliary systems. They therefore need less than half of the energy to satisfy the building's demands.

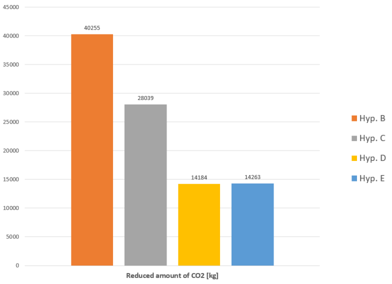

Figure 15: Reduced amount of CO2 per system

Another important aspect is the determination of the impact on the reductions in greenhouse gas emissions, in kilograms of CO_2, through the implementation of alternative systems compared to the current natural gas system. The *Polysun* program allows determining the amount of CO_2 reduced against the current system, in the use of each system. Figure 15 shows the value for each of the options.

The Hypothesis B presents a value of 40255 kg, being this the highest, because the production of the photovoltaic panels represent a great percentage of this number. Following the option B are the 34577kg per year by the thermal collectors, being that the two last hypotheses present similar values, around 14000 kg saved per year.

6. Conclusions

With this study it was possible to evaluate the implementation of alternative technologies, namely Heat Pumps and Solar Systems as energy efficiency improvement in the dormitory of the Military Academy building. The thermal needs were obtained through regulated Orders in the Portuguese Official Gazette and the analysis of studies carried out with similar purposes. The program Polysun was used for the sizing of the implemented systems. Analyses of climate, geology and local studies allowed a greater accuracy in the realization, reducing uncertainties in the design and economic viability of each option.

In terms of energy, a water demand was calculated taking into account only and exclusively the bathing of the Academy's students. A consensus was reached through questionnaires to students, teachers and consultations with studies in the area of energy consumption, and a value of 1.5 baths per student per day was obtained. This figure is equivalent to 1790 m^3 of water with a safety factor of 20%. However, the simulation obtained values above the theoretical value of 40.25 MWh of DHW consumption, with a maximum of 50.68 MWh and a minimum of 42 MWh, despite the configurations being equal for each hypothesis. A measure to combat the high water consumption associated with DHW would be the incorporation of low flow showerheads, with values of 6.5 - 8.5 L/min and not the 10 L/min dimensioned for this study.

In the case of the economic factors, the alternatives showed great savings compared to the system already installed, presenting a difference of 83538 € for the most expensive alternative within the alternative options presented. The solar systems showed small differences, with a maximum of 8412 € between them. Despite studies pointing BCG as the best option compared to air source heat pumps, in this case and in monetary terms, the air-to-water heat pump emerged as the most viable option. Hypothesis E, solar thermal with the aid of an air-to-water heat pump, proved to be the most viable option with an annual revenue of 865 €, not counting the decennial costs, and thus, an accumulated expense lower than the initial investment with a value of 62119 €. The bet on thermal collectors, in combination with a low power and low cost heat pump, shows a lot of potential for the case study.

The alternatives demonstrated a large reduction in terms of fuel and in the amount of CO2. A maximum saving of 40255 kg/year CO2 and 58.10 MWh/year fuel was obtained.

In the case of Hypothesis B, the use of the surplus energy will make this option even more attractive, being able to be used for injection in the network and obtaining this revenue, or else an implementation of a battery system so that the complete DHW system becomes self-sufficient. Further study of this system may reveal interesting conclusions in economic, energy and ecological terms.

An important criterion to take into account for future dimensioning will be the amount of thermal losses for each system. The simulation showed a decrease of 22% compared to an increase of 50% in the insulation thickness of the pipes. Further measures can be implemented to make this reduction even more significant and contribute to a more efficient total system.

An extremely relevant point when sizing systems will be the daily water consumption. Something to take into account if you want to continue with this project in the future, or with a project in the same area, will be the accurate accounting of the amount of water spent per occupant. If we don't have an exact value, it will be difficult to make a dimensioning without having deficits or excesses, both energetic and economical. Besides, the access to data on energy costs, equipment specifications and actual consumption readings have made the accuracy of sizing even greater.

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