Improvement of Energetic Efficiency of Buildings: Contributions of Passive and Active Solutions

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**Abstract:** The building sector has a significant weight in energy consumption and a high potential for increasing its energy efficiency. With the enforcement of the energetic certification, it has been tried to find and select different solutions that presents less energy consumption and waste, which translates into an effective reduction of CO2 emissions. It is in this perspective that this work fits, since its aim is to evaluate the contribution of passive and active solutions of a hotel located in Portugal, for the improvement of the energetic efficiency, as well as to evaluate the contribution of some renewable energy sources. Besides, the cogeneration remains as the most effective technology on the conversion of primary energy into electricity and heat. The application of cogeneration technologies in the buildings sector gains notability facing the rise of fuel prices. To improve the building performance, there were made several changes on the dynamic model used with the goal of evaluating the contribution of different solutions. It was concluded that they contribute to a reduction of thermal needs of 25.2% and avoided emissions of equivalent tons of CO2 of 30.4%.The analysis of the technical/economic viability of the implementation of the CHCP becomes feasible with an absorption chiller to produce cooling. The payback period is less than 8 years which proves that it is an economic viability of this technology.

**Key words:** CHCP, energy analysis, avoided CO2 emissions, economic analysis

1. Introduction [[1]](#footnote-2)

Hotels are buildings which have high energy demands and water consumption that decisively reflects in operating costs. It is in the tertiary sector are great potentials for improving energy efficiency.

It is thus essential to develop a sustainable strategy to keep in account the environmental, social and economic impact of all and each one the parts that make up the building. In this sense, energy optimization and resources plays a major role in driving the operation of buildings. These concerns must be present and reflect up from the design phase, that is, in the early stages of development of their project. The energy optimization is to select the solutions that promote the reduction of energy consumption, waste and a reduction of emissions of greenhouse gases (CO2).

It should be noted that the energy optimization of a building does not pass only by mandatory large measures with high energy impacts and operating costs. It is many sometimes the result of the adoption of small actions that represent small impacts, the sum which are of importance for the intended purpose — to reduce energy consumption and associated operating costs.

Despite the importance assumed by using renewable energies in the third sector, cogeneration remains as the most effective technology on the conversion of primary energy (fossil or renewable sources) into electricity and heat [1, 2]. The application of cogeneration technologies on the third sector gains notability facing the rise of fuel prices and the need to ensure adequacy and comfort of spaces [3-6].

The micro-power generation [7], as an activity for low tension electricity production with the possibility of energy delivery to the public grid, was regulated by several Decree-Laws [8, 9]. The actual ordinance stipulates that the electricity produced is destined predominantly for their own consumption, and the surplus that can be delivered to third parties or to the public, with 150 kW limit in the case of power delivery to be made public. For the production of electricity on a large scale, using photovoltaics systems, the remuneration given to national electric system network is regulated by Decree-Law No 225/2007 of 31 May, [10]. Thus, the use of photovoltaic panels is becoming increasingly common practice more visible in several countries. So along with energy efficiency measures, the increasing integration of renewable energy in buildings, fits to aims to reach the 2020 targets stipulated. The energy consumption of the building is directly related to passive and active the solutions that will be analyzed.

In this work a hotel located in Portugal was studied. The dynamic codes TRACE700 v. 6.2.5 and TSOL were used respectively for the evaluation of energy needs in HVAC system and for sanitary hot water demand. It was verified that the higher consumptions were on the electric ones, specifically the one of lightning (32.4%) and the equipment’s (25.8%), followed by the HVAC, ventilation (11.6%) and cooling (10.8%). To analyze the contribution of different solutions, in order to increase the energetic efficiency of the hotel, there were made several changes on the transient computer model. The analysis of the technical/economic viability of the implementation of a cogeneration/trigeneration becomes at two levels, where the technologies tested were analyzed to adapt them to the thermal needs of the building. Among several solutions, namely micro turbines and fuel cells, it was chosen a system based on an internal combustion engine running on natural gas, with the help of an absorption chiller to produce cold. The payback period of this solution is less than 8 years.

2. Parameters to be Evaluated

Pay back time: is the project’s operating time

necessary to obtain the sum of revenue and expenditure flows that equalize the value of the investment:

$$Payback=\frac{Initial Investment}{Annual Revenues}$$

Energy Efficiency Index (EEI) [kgep.m-2.year-1]. According to Decree-Laws already specified, there are several formulas to evaluate the EEI (not shown here) and deals with specific consumption for heating, cooling and lighting, for each typology. This parameter is important in order to define in which energy classes the building belongs.

EEE (Equivalent Electrical Efficiency). By the Decree Laws in force, this parameter is given by:

$$EEE=\frac{E}{C-\frac{T}{0.9-0.2\frac{CR}{C}}}\geq 0.55$$

Where:

E [kWh]: electricity generated annually by the cogeneration system, excluding the consumption in internal auxiliary power generation systems;

T [kWh]: useful thermal energy consumed annually from the thermal energy produced by cogeneration, excluding the consumption in the internal auxiliary power generation systems;

C [kWh]: the primary energy consumed annually in the cogeneration system, evaluated from the lower heating value of fuel and other resources used;

CR [kWh]: equivalent energy of renewable resources or industrial waste, agricultural or urban consumed annually in cogeneration facility.

EEE can assume the following values, according to the same Decrees-Laws:

EEE ≥ 0.55 for installations using natural gas as fuel, gas petroleum or liquid fuels with the exception of fuel;

EEE ≥ 0.50 for installations using fuel oil as fuel, alone or together with waste fuels;

EEE ≥ 0.45 for installations using biomass as fuel or residual fuels, alone or in conjunction with a fuel support, a percentage not exceeding 20% annual average.

For the case study, it will not be analysed the contribution of renewable resources. Thus the formula for calculating the EEE is reduced to the following expression:

$$EEE=\frac{E}{C-\frac{T}{0.9}}\geq 0.55$$

For the CHP and CHCP the following parameter must also be evaluated.

Electrical efficiency, *electrical*:

ηelectrical = Egrosselctricity/Total fuel consumed

Thermal efficiency, *thermal*:

*ηthermal* = *Egross thermal*/Total fuel consumed

Eer: maximum quantity of electricity to provide annually to the Electric System of Public Service not higher than the value given by the following equation:

$$E\_{er}=\left(4.5\frac{E+T}{E+0.5T}-4.5\right)E$$

Saving Energy Index (ESI): ratio of the fuel economy obtained in the cogeneration engine when compared to the amount of fuel consumed in a conventional installation, i.e. an electrical plant with an efficiency *ηc*, a boilerwith an efficiency *ηb* and an electric chiller with a COPcomp. It is given by the following expression:

$$ESI=1-\frac{1}{\frac{η\_{e,C}}{η\_{c}}+\frac{η\_{e,C}xRCE}{η\_{b}}+\frac{η\_{e,C}xRFE}{COP\_{comp}}}$$

Where:

RCE and RFE are respectively the ratios between heat and electricity and the ratio between cooling and electricity in the CHCP;

3. Annual Thermal Analysis of the Hotel

In the base case, it was followed the RCCTE (Council Regulation of the Characteristics of the Thermal Behavior of Buildings). The U values of the internal and external envelope was calculated and are shown in Table 1.

As already mentioned, the energy needs of the hotel were simulated with the dynamics codes TRACE700 v.

**Table 1 U values [Wm-2ºC-1] for the base case.**

|  |  |  |
| --- | --- | --- |
|  |  | U values [Wm-2ºC-1] |
| External envelope | Walls | 1.8 |
| Roof and floor | 1.25 |
| Internal envelope | Walls | 2 |
| Roof and floor | 1.65 |

6.2.5 and TSOL, the results being displayed in Table 2. It is also shown the values of EEI as well as the emitted CO2 associated with the energy consumption.

It must be noticed that the electric heating corresponds to the consumption of operation of heating systems, including pumps condensate, burner and control panel of the boilers. The gas heating corresponds to the consumption of boilers, with an efficiency of 83.3%, and cooling corresponds to the electrical consumption of chillers with a COP of 3.2. The ventilation represents the consumption of the air handling equipment, while the pumps corresponds to the consumption associated with all fluid pumping equipment.

The maximum thermal power loads for heating and cooling are respectively equal 1775.8 kW and 1920.1 kW. The values given above were obtained with a reference system composed of an electric air-to-air chiller (COP of 3.2) and a conventional boiler with an efficiency of 83.3%. It should be noted that the electric heating, represents the consumption of operation of heating systems, including pumps condensate, the burner and control panel of the boilers. The gas heating represents consumption of boilers and the cooling corresponds to the electrical consumption of chillers.

Is important to highlight that the “parameters” which most contribute to the nominal consumption of primary energy are the lighting consumption and electrical equipment. Also, it is noted that the building presents an elevated energy consumption, due to the fact it is a large service building. However, even in the base case on predefined conditions, the building is already within the minimum required by RSECE [11].

The annual energy bill and associated costs are shown in Table 3.

**Table 2 Annual thermal needs of the hotel (base case).**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Useful thermal needs [kWh.year.1] | Nominal primary thermal energy [kgep.year-1] | EEI [kgep.m-2.year-1] | CO2 emissions[tons CO2] |
| H&C | Heating | Electric | 19724 | 5720 | 0.27 | 6.9 |
| Gas | 246731 | 21219 | 1.0 | 25.3 |
| Cooling | 521389 | 151203 | 5.19 | 181.4 |
| Others | Lighting | 1141168 | 330939 | 15.61 | 397.1 |
| Electric equipment | 909071 | 263631 | 12.43 | 316.4 |
| Gas equipment | 439081 | 37761 | 1.78 | 45.3 |
| Ventilation | 498000 | 144420 | 5.56 | 173.73 |
| Pumps | 238800 | 69252 | 2.67 | 83.1 |
| Hydraulic equipment | 4729 | 1371 | 0.06 | 1.6 |
| SHW | Gas | 636318 | 54723 | 2.58 | 65.7 |
| Electric | 10143 | 2941 | 0.14 | 3.5 |
| SPH | Electric | 4840 | 1404 | 0.07 | 1.7 |
| Gas | 161678 | 13904 | 0.66 | 16.7 |
| Mechanical equipment | 6572 | 1906 | 0.09 | 2.3 |
| Total | 4.84 [GWh .year-1] | 1100[tep.year-1] | 48.1 | 1320.5 |

**Table 3 The annual energy billing and associated costs.**

|  |  |  |
| --- | --- | --- |
|  | Total thermal load [MWh/year] | Fuel Bill [€/year] |
| Electricity | 3354.43 | 275890 |
| Gas | 1483.81 | 46148 |
| Total | 4838 | 322038 |

4. Improved passive solutions

4.1 Opaque Envelope

The interior space of the building is physically separated from the outside by an envelope that is composed of opaque (walls, roof, and floor) and a transparent part (glazing). Note that for this first analysis, to the glazed envelope have been given the maximum permissible values of solar factor and heat transfer, set out in RCCTE [12]. In order to improve the efficiency of the building, regarding the opaque envelope, four alternatives were proposed. These ones are only due to changes of the U value of the internal and external opaque envelope due to the changes in thermal insulation. The alternatives are (always according to RCCTE):

Alternative 1 (ALT 1): the U values are the reference ones;

Alternative 2 (ALT 2): 25% improvement on the reference values;

Alternative 3 (ALT 3): 50% improvement on the reference values;

Alternative 4 (ALT 4): 75% improvement on the reference values;

The alternatives are shown in Table 4.

The values in parenthesis correspond to the reduction of heat transfer coefficients between the alternatives. From this analysis it is emphasized that the greatest reduction occurs between the base case and alternative one.

The optimization process of the opaque envelope, goes through the analysis of its contribution to the energy consumption of the building. Table 5 shows the annual energy consumption of the hotel regarding the alternatives for the opaque envelope as well as the values of EEI and the emitted CO2 associated with the energy consumption. There are also shown the total costs and the payback time of all alternatives.

**Table 4 U values [Wm-2ºC-1] for the base case and for four different alternatives.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Base case | Alt 1 | Alt 2 | Alt 3 | Alt 4 |
| External envelope | Walls | 1.8 | 0.7 (61%) | 0.525 (25%) | 0.35 (33%) | 0.175 (50%) |
| Roof and floor | 1.25 | 0.5 (60%) | 0.375 (25%) | 0.25 (33%) | 0.125 (50%) |
| Internalenvelope | Walls | 2 | 1.4 (30%) | 1.05 (25%) | 0.7 (33%) | 0.35 (50%) |
| Roof and floor | 1.65 | 1 (39%) | 0.75 (25%) | 0.5 (33%) | 0.25 (50%) |

**Table 5 Annual thermal needs of the hotel: base case simulation and alternatives for the opaque envelope.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Base case | Alt 1 | Alt 2 | Alt 3 | Alt 4 |  |
| Heating | Electric | 0.27 | 0.25 | 0.24 | 0.22 | 0.22 | Kgep.m-2year-1 |
| Gas | 1 | 0.36 | 0.27 | 0.2 | 0.15 |
| Cooling | 5.19 | 4.59 | 4.53 | 4.48 | 4.45 |
| Ventilation | 5.56 | 4.99 | 4.97 | 4.87 | 4.91 |
| Pumps | 2.67 | 1.41 | 1.38 | 1.37 | 1.37 |
| EEInominal | 48.1 | 44.99 | 44.77 | 44.53 | 44.49 |
| Consumption | 1100.4 | 1029.5 | 1026 | 1021.6 | 1022 | tep.year--1 |
| Total Energy | 228 | 211 | 210 | 209 | 208 | kWh.m-2.year-1 |
| CO2 emissions | 1320.5 | 1235.4 | 1231.2 | 1225.9 | 1223.4 | tons CO2 equiv.year-1 |
| Costs | - | 104.5 | 189.4 | 316.4 | 845.5 | [€.103] |
| Payback time |  | 5.6 | 9.6 | 15.1 | 40.4 | Years |

The baseline for this analysis is the opaque envelope, the base case, from which follows that it is not relevant to improve the U value of the opaque envelope beyond the reference values stipulated by RCCTE, since the decrease of the U values of the opaque envelope, beyond the benchmarks, do not translates into a significant improvement of the final value of the primary energy consumption (Table 5, consumption: between Alt 1 and Alt 4 the difference is 0.73%). As can also be observed in the same table, it is apparent that the transition of the U values of the opaque envelope when compared with the alternative one (ALT 1), presents a decrease in the consumption, both for heating (4.27%) and cooling (14.3%) and consequent reduction of ventilation and pumping systems. As can be seen, alternative 1 is the best one when compared to the base case, even due to the payback time. Besides these benefits there is no improvement in the energetic classification of the hotel (to reach class B the EEI should be less than 44.1 Kgep.m-2.year).

4.2 Opaque Envelope

As the best solution for the opaque envelope is alternative 1, its values were fixed in order to evaluate the alternatives for different types of glazing and frames. With the code Calumen of Saint-Gobain there were analyzed four different alternatives of double glazing regarding the Solar Factor (SF):

Alternative 1 (ALT 1): SF = 0.45

Alternative 1 (ALT 2): SF = 0.4

Alternative 1 (ALT 3): SF = 0.35

Alternative 1 (ALT 4): SF = 0.3

For each alternative, there were analyzed different frames being them metallic with or without thermal cut or of wood or plastic. The energetic and economic analysis are displayed respectively in Table 6 and Table 7.

From the results of the analysis it is concluded that a window with a low solar factor there is a reduction in thermal cooling requirements. However, it causes increased heating requirements, leading the need to find an optimal point associated with the improvement of the glazed envelope. It was chosen a glass with a solar factor 0.40, since this solution becomes attractive in terms of payback time.

**Table 6 Cost savings using glazed envelope with different frames.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Double glazing | Type of consumption | Annual energetic consumption[MWh.year-1] | Annual energetic costs[€.103.year-1] | Total[€.103.year-1] | Cost savings[€.103year-1] |
| Frame | SF |
| Base case (0.56) | Electricity | 3157 | 262 | 303.4 | - |
| Gas | 1327 | 41.6 |
| Metal without thermal cutting | 0.45 | Electricity | 3105 | 258 | 300 | 3.6 |
| Gas | 1329 | 42 |
| 0.4 | Electricity | 3068 | 255 | 297 | 6.2 |
| Gas | 1332 | 42 |
| 0.35 | Electricity | 3036 | 253 | 295 | 8.3 |
| Gas | 1336 | 42 |
| 0.3 | Electricity | 3005 | 251 | 293 | 10.4 |
| Gas | 1338 | 42 |
| Metal with thermal cutting | 0.45 | Electricity | 3118 | 259 | 300 | 2.9 |
| Gas | 1321 | 41 |
| 0.4 | Electricity | 3084 | 257 | 298 | 5.2 |
| Gas | 1322 | 41 |
| 0.35 | Electricity | 3118 | 259 | 300 | 7.6 |
| Gas | 1323 | 41 |
| 0.3 | Electricity | 3020 | 252 | 294 | 9.7 |
| Gas | 1325 | 42 |
| Wood | 0.45 | Electricity | 3131 | 260 | 301 | 2 |
| Gas | 1318 | 41 |
| 0.4 | Electricity | 3097 | 258 | 299 | 4.5 |
| Gas | 1318 | 41 |
| 0.35 | Electricity | 3064 | 255 | 297 | 6.8 |
| Gas | 1318 | 42 |
| 0.3 | Electricity | 3031 | 253 | 294 | 9.1 |
| Gas | 1319 | 41 |
| Plastic | 0.45 | Electricity | 3139 | 261 | 302 | 1.5 |
| Gas | 1317 | 41 |
| 0.4 | Electricity | 3100 | 258 | 299 | 4.3 |
| Gas | 1317 | 41 |
| 0.35 | Electricity | 3066 | 255 | 297 | 6.7 |
| Gas | 1317 | 42 |
| 0.3 | Electricity | 3033 | 253 | 294 | 9 |
| Gas | 1318 | 41 |

**Table 7 Payback time of different kinds of windows.**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Total costs [€.103] | Increase in investment [€.103] | Payback time [years] |
| SF |  |  |  |
| Base case (0.56) | 332 | - | - |
| 0.45 | 362 | 30.2 | 8.4 - 19.7 |
| 0.4 | 377 | 45.3 | 7.3 - 10.6 |
| 0.35 | 407 | 75.4 | 9.1 - 11.3 |
| 0.3 | 422 | 91 | 8.7 - 10.0 |

5. Improved Passive Solutions

5.1 Solar thermal panels for sanitary hot water and swimming pool and PV´s for electricity production.

Decree-Law No. 79/2006 turns out the compulsory installation of solar panels for hot water in new buildings or major rehabilitation of buildings. In this hotel they will be used for sanitary hot water and swimming pool. The main characteristics of the solar thermal panels are: optical yield of 0.74, a solar capture area of 2 m2 and a thermal loss coefficient a1 = 3.9 W/m2/K and k2 = 0.013 W/ m2/k2.

An economic study was also done, similar to the previous cases. For the building under consideration, if using a solar capture area higher to 200 m2, the system is no longer economically viable because the payback time is greater than the lifetime of the equipment. It should be noted that the selection criteria of this type of equipment cannot be only based on an economic assessment. It should also be taken into account the energy contribution that this type of equipment has to each situation under review. The lower payback time is around 8 years which corresponds to an area of 25 m2. For this situation, the EEI is 41.5 Kgep.m-2.year-1 and becomes less than the reference value, 44.1 Kgep.m-2.year-1. So the hotel can be included in class B.

The PV panels, in despite of the high initial investment, is ecologically clean, with long life and do not require great care in terms of maintenance. For the contribution of this technology in the building, the analysis was done according to the maximum power peak of the photovoltaic system to be used, where it was tested the contribution of three different types of panels, such as amorphous silicon ones, the polycrystalline silicon and their integration in the facades (BiPV). The results of the comparison between them are shown in Table 8. The BiPVwas discard from the analysis because the modules are arranged vertically which harms much the production of these panels.

**Table 8 Comparison between solar thermal panels: amorphous silicon, and polycrystalline silicon.**

|  |
| --- |
| Amorphous silicon panels |
| Power peak [kWp] | - | 3.68 | 10 | 20 | 30 | 100 | 150 |
| Solar capture area [m2] | - | 62.92 | 171.6 | 343.2 | 500.5 | 1716 | 2516.8 |
| Nº of modules | - | 44 | 120 | 240 | 350 | 1200 | 1760 |
| Produced energy [MWh.year-1] | - | 6.6 | 18.3 | 36 | 53 | 186 | 268 |
| EEInominal[Kgep.m-2year-1] | 44.25 | 44.16 | 44 | 43.8 | 45.6 | 42 | 41 |
| Polycrystalline silicon panels |
| Power peak [kWp] | - | 3.68 | 10 | 20 | 30 | 100 | 150 |
| Solar capture area [m2] | - | 28.9 | 76.9 | 147 | 368 | 736 | 1088 |
| Nº of modules | - | 18 | 48 | 92 | 230 | 460 | 680 |
| Produced energy [MWh.year-1] | - | 6.9 | 19 | 35 | 89 | 182 | 270 |
| EEInominal[[Kgep.m-2year-1] | 44.25 | 44.16 | 44 | 43.8 | 41 | 42 | 41 |

From the results obtained for the two types of photovoltaic panels, it was concluded that for the same peak power, the annual energy produced by amorphous silicon panels and the poly-crystalline silicon is quite similar between them, which is reflected in a decrease the overall consumption of the building in a very similar manner. Although these two different types of panels has for the same peak power a very similar annual energy production, the amorphous silicon panels are penalized because they require more than twice the solar capture area. So it was chosen for the following analyses the polycrystalline silicon panels — 92 modules with a power pick of 20 kWp. The EEI is 42 Kgep.m-2 .year-1 which maintains the hotel in class B, beside the benefits shown in Table 8.

5.2 Other Improvements

Several other improvements were taken into account. In order to not repeat the same kind of tables, only the final results of each one will be shown in this subsection.

- Ventilation devices

In order to improve the efficiency of ventilation equipment, consideration will be given to influence of HVAC systems with and without heat recovery, as well as the influence of consumption of the equipment associated with them. Between several options, the final one was that the air velocity in the batteries (heating and cooling), did not exceed 2.5m.s-1 whit the respective reduction of the total pressure drop in ducts and with heat recovery. Comparing with the base case, the percentage of the total energy saved is 2.9%, and the avoided CO2 emissions represents 4.1%. The EEI value is 42.79 Kgep.m-2.year, less than the reference value.

- Lighting control equipment – Dimmers. The control of artificial lighting in a building aims to maximize the use of natural lighting, requiring only lighting and occupancy sensors in the spaces. These detect the presence of space lighting power, comparing it with the preset. If it is not achieved by natural lighting is driven artificial lighting. The TRACE 700 software has an algorithm that allows the inclusion of the concept of natural light into the building, creating in each space a variable named daylight factor, defined by the ratio between indoor luminance and the horizontal exterior luminance. The implementation of such control systems, reverts in a reduction of the annual energy bill of around 7%. The contribution to this decrease comes from the electricity consumption that is reduced considerably due to lower power consumption in the building using this technology. The payback time is 1.3 years.

- Chillers using heat recovery of hot water from the condensers to heat the sanitary hot water (SHW). After an energetic and economic analysis, it was found out that using this technique, there is an expected increase in power consumption by the latter, by the reason of its contribution to the SHW (there is a significant reduction in nominal power to SHW). The greatest contribution of this equipment to satisfy the SWH takes place in the cooling season (summer), since in this period the chillers are running permanently (feeding the cooling batteries).

- Condensing boilers. They take advantage of the flue gas from the combustion. The use of condensing gas boilers leads to a decrease in overall building consumption due to better performance they have when compared to conventional boilers.

5.3 Overall Solutions

Taking into account the better solutions for each active solutions shown before, it’s possible to compare them with the initial conditions. Table 9 displays the overall results of the best choices in order to reduce the energy consumption of the building.

As can be seen, with the features inherent in the initial solution (base case) when compared to the optimal solution set, the differences in all consumption levels decrease in a meaningful way. The reduced overall consumption of the building is approximately 25%. For the base case an according to the Portuguese legislation, the energy rating of the hotel was B- category. Therefore, after the changes carried out the building was rated to class A.

6. Cogeneration (CHP) and Trigeneration (CHCP)

Depending on the electrical power of the engine to be used and of the annual operating hours of the system, it’s possible to evaluate the electricity produced annually by the equipment. In turn, the useful thermal energy depends on the thermal requirements of the building, because such a system only produces heat (besides the electricity). To be able to produce cooling it is necessary to have an absorption chiller that runs with the heat generate by the CHP. In this case such systems are designated as trigeneration systems — Combined production of Heat, Cooling and Power (CHCP). In the case study, due to the involved thermal needs, is interesting to couple an absorption chiller for the cooling needs.

There were analyzed several types of cogenerations systems, namely four strokes engines running with natural gas, micro turbines and fuel cells. Among them, the one that better fits to the thermal needs of hotel is a specific one with the following characteristic as shown in Table 10.

**Table 9 Results of the final solution.**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Final solution | Initial solution | Reduction of energy consumption | Avoided emissions of CO2 |
| [kgep .m-2.year.-1] | tons CO2 | [kgep.m-2.year-1] | tons CO2 | % [-] | % [-] |
| Heating | Electric | 0.27 | 6.8 | 0.27 | 6.9 | 1.6 |  |
| Gas | 0.36 | 9.1 | 1.0 | 25.3 | 64.2 |
| Electric Cooling | 4.49 | 157 | 5.19 | 181.4 | 13.5 |
| Lighting | 12.95 | 329 | 15.61 | 397.1 | 17.1 |
| Electric equipment | 12.43 | 316.4 | 12.43 | 316.4 | - |
| Gas equipment | 1.78 | 45.3 | 1.78 | 45.3 | - |
| Ventilation | 2.62 | 85.8 | 5.56 | 173.73 | 52.9 |
| Pumps | 0.52 | 16.9 | 2.67 | 83.1 | 80.7 |
| Hydraulic equipment | 0.03 | 0.08 | 0.06 | 1.6 | 46.5 |
| SWH | Gas | 0.54 | 13.7 | 2.58 | 65.7 | 79.1 |
| Electric | 0.14 | 2941 | 0.14 | 3.5 | 0.9 |
| SPH | Electric | 0.07 | 1.7 | 0.07 | 1.7 | 5.4 |
| Gas | 0.52 | 13.1 | 0.66 | 16.7 | 21.9 |
| Mechanical equipment | 0.09 | 2.3 | 0.09 | 2.3 | 0.1 |
| Solar thermal | -0.32 | -8.1 | - | - | - |
| PV | -0.48 | -12.1 | - | - | - |
| Total | 36 | 918.8 | 48.1 | 1320.5 | 25.2 | 30.4 |

**Table 10 Characteristics of the CHP engine.**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Electric power [kW] | Thermal power [kW] | Gas consumption [kW] | Electric efficiency [%] | Thermal efficiency [%] | Global efficiency [%] |
| 330 | 363 | 851 | 38.78 | 42.66 | 81.43 |

It should be noted that the operating system defined for the system CHCP is that the heat produced by the system first meets the heating needs, and only supplies heat to the absorption chillers to satisfy the cooling demands with the surplus heat not used in heating.

In order to verify the feasibility of this type of system, it is necessary to define its annual operating hours, which for the case study, will be analyzed three different possibilities. It runs 24 hours a day (8760 h/year), or from 7 am to 24 hours (6205 h/year) because this schedule eliminates much of the super-peak and standard empty electricity (uninteresting of the remuneration level), or from 10 am to 21h (4380 h/year). Table 11 shows the contribution of the CHCP when compared to the base case.

For the chosen engine, the EEE value is checked (EEE ≥ 0.55) using just one or two engines. It is also be concluded that the use of this engine and its hours operation, there is the economic viability of this technology as well as the obligation to use it (payback time < 8 years).

**Table 11 Contribution of the CHCP for the energetic needs as a function of the running hours per year.**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Thermal needs | CHCP | Conventional system | CHCP | Conventional system | CHCP | Conventional system |
|  | % | % | % |
| Heating | 94.28 | 5.72 | 70.97 | 29.03 | 41.75 | 58.25 |
| Cooling | 39.32 | 60.68 | 39.22 | 60.78 | 41.12 | 58.88 |
| Annual operating hours | 8760 h year-1 | 6205 h year-1 | 4380 h year-1 |

7. Conclusions

In this work it was carried out an energetic and economic analysis of the contribution of passive and active solutions for buildings in order to reduce its energy consumption as well as the avoided CO2 emissions. The contribution of renewable energy sources and the assessment of the contribution of a CHCP system was also studied. For that, dynamic codes were used to obtain all the thermal needs of a hotel located in Portugal.

The simulations with nominal conditions (base case) showed that the total energy consumed in the building is 4.84 GWh/year, where under the conditions set for this model, it achieved a EEInominal of 48.1 kgep.m-2.year-1, indicating that the building features an energy rating of B- [EEI nominal (48.10) < EEIreference (49.02) kgep.m-2.year-1. Regarding the emission level of CO2, this building would emit 1320.5 equivalent tons of CO2 per year. The consumption of HVAC (heating, cooling, ventilation and pumps), represents 35.7% of primary energy consumption, lighting 30.1%, consumption on the equipment is 27.6% and 6.6% referred to sanitary hot water and swimming pool water.

At a passive level, a sensitivity analysis to the base case was also done. Regarding the changes in the opaque envelope, the best solution was ALT1 shows a decrease in the consumption, both for heating (4.27%) and cooling (14.3%) and a consequent reduction of ventilation and pumping systems. The avoided CO2 emissions are 6.4% and the payback time is 5.6 years. Regarding the glazing envelope and from the results of the analysis it is concluded that a glass with a solar factor of 0.40 is the best one, since this solution becomes attractive in terms of payback time in the range of 7.3-10.6 years as a function of the different types of frames that can be used.

At an active level it was analyzed the use of solar thermal panels for hot water heating. The lower payback time is around 8 years. For this situation, the EEI is 41.5 Kgep.m-2.year-1 and becomes lower than the reference value, 44.1 Kgep.m-2.year-1.Also two types of photovoltaic panels were analyzed: amorphous silicon and poly-crystalline silicon. It was concluded that the amorphous silicon panels are penalized because they require more than twice the solar capture area. So it was chosen the polycrystalline silicon panels whit 92 modules. The power pick is 20 kWp and the EEI is 42 Kgep.m-2.year-1. With this solution, it was concluded that they contribute to a reduction of thermal needs of 25.2% and avoided emissions of equivalent tons of CO2 of 30.4%. Regarding the use of CHCP the best solution chosen was a four stroke internal combustion engine running with natural gas, and coupled to an absorption chiller. The contribution of this type of engine to fulfill the heating requirements of the building lies in the range of 44 to 94% and for cooling the range is 39-61% (depending upon the working system profiles). It is also concluded that, the use of this engine and its operating hours, there is the economic viability of this technology as well as the obligation to use it (payback time < 8 years).

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