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Energetic analysis of the implementation of renewable energies in a Canary Island Hotel

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Abstract

The European Directive on Energy Performance of Buildings has established a target of Nearly Zero-Energy Buildings (nZEB) for a sustainable future. For this target, hotels take a special interest, as shown in the neZEH project (Nearly Zero Energy Hotels project) (neZEH, 2016), (Tsoutsos et al., 2013). In this work, a hotel located in Tenerife (Canary Island, Spain) is analyzed. With the objective of reaching the nZEB label, an exhaustive energetic analysis of the hotel was performed and the implementation of different renewable energy systems was proposed. The utilization of solar thermal collectors, photovoltaic collectors and heat pumps are analyzed in this work. Also, the passive solar characteristics, namely related to internal shading, were considered.

Keywords: *hotel, renewable energies, island, energy performance, TRNSYS*

1. Introduction

Buildings consume 40% of the total energy and emit 36% of greenhouse gases in Europe, therefore representing a high potential for energy savings. Specific measures to reduce energy consumption in the building sector have been introduced by the European Union with the European Directive on Energy Performance of Buildings in 2002 (EU Directive, 2002) and its recast in 2010 (EU Directive, 2010). These directives have established a target of Nearly Zero-Energy Buildings (nZEBs) for a sustainable future. The implementation of nZEB as the building target from 2018 onwards represents one of the biggest challenges to increase energy savings and minimize greenhouse gas emissions (Delia, 2015). An nZEB is a building that “has a very high energy performance with a low amount of energy required covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby” (EU Directive, 2010). However, the concept of nZEB is still not well developed in most EU countries. Large scale renovations of existing buildings towards Zero Energy are in the forefront of the European Union and national policies. For this goal, longstanding hotels located in places with high solar exposition take a special interest for the implementation of renewable technologies.

To know the energy performance of a hotel, and if it should be a nZEB, it is necessary to analyze the amount of energy consumed by the hotel from conventional sources and renewable sources (if any renewable systems are installed). In this work, for a given hotel and after this analysis, the possibility of using alternative renewable sources to replace conventional ones is proposed.

2. Building description

In this work, a hotel located in Tenerife (Canary Island, Spain) was analyzed. The location and a hotel view are shown in figure 1. The hotel is located 99 m above the sea level and 1.4 km from the coast. The hotel main façades are 29ºNW oriented. It is surrounded by gardens, with very high solar exposition (no significant shading from the surroundings). The latitude and longitude of the place are 28.4ºN and 16.2ºW, with sub-tropical climate. Using the METEONORM software, the meteorological data of the local were obtained. At the hotel location, the annual horizontal incident solar radiation is 1640 kWh/m^2 and the annual average temperature is 21ºC.

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Fig. 1: Hotel location in Tenerife Island and hotel view.

The hotel was opened in 1959 and renovated by July 2015. This is a medium size hotel with high standards regarding the environment. The hotel management has been certified several times and received different awards from 1995 until today, always with the motivation to have a sustainable hotel. The hotel category is 4 stars, with 83 rooms distributed in 4 floors, ground floor and cave, with 5940 m^2 of net floor area. The east and west façades are characterized by extensive glazed areas and balconies with high solar exposition. The characteristics of each floor, such as floor areas, façade areas and percentage of glazed area per façade area, are shown in Table 1. The façade areas are detailed for each orientation (N: North, S: South, E: East and W: West).

Tab. 1: Characteristics of the different floors of the hotel.

Floors	Floor area (m^2)	Façade area (m^2)				Glazed area / Façade area (%)			
		N	S	E	W	N	S	E	W
Cave	1482	106	28	247	247	85	0	13	39
Ground floor	1278	75	75	171	165	63	56	50	52
Floor 1	840	53	53	144	144	16	0	38	50
Floor 2	840	53	53	144	144	16	0	38	50
Floor 3	840	53	53	144	144	16	0	38	50
Floor 4	660	45	45	132	132	36	48	0	71

The external walls of the hotel are massive and constituted by plaster, two concrete layers and insulation between the concrete layers, with a total thickness between 37 cm and 47 cm, depending on the floor, and U-value of 0.70 W/m^{2}K approximately. The other U-values are: 0.49 W/m^{2}K for the ground and 0.35 W/m^{2}K for the roof. All windows have double glazing with a U-value equal to 3.21 W/m^{2}K and a g-value equal to 0.72.

The hotel has unglazed solar thermal collectors to heat the water of the external swimming pool, and flat plate collectors (FPC) to heat the water consumed in the hotel, as can be seen in figure 2. The thermal collectors installed on the roof have a useful area of 117 m^2 and an annual heating useful energy of 107 MWh/year. The average occupancy of the hotel is 138 guests per day during the year.

Fig. 2: Top view of the hotel with the solar thermal collectors on the roof (GoogleEarth).

For the air-conditioning, a new Water-Sourced Liquid Chiller/Heat Pump (Carrier 61W) was installed in 2014, with 99 kW of heating capacity ($COP_{heating}$ = 3.1) and 67 kW of cooling capacity ($COP_{cooling}$ = 2.1), in the most unfavorable case (condition in heating mode: condenser water entering/leaving temp.=55ºC/65ºC).
For both water and air heating applications, the strategy at the hotel is to use the solar thermal collectors (FPC), the heat pump and only after the diesel boiler (as backup). When solar radiation is not enough to heat the swimming pool, the diesel boiler is also used. In the kitchen only propane is used.

3. Modelling system

The hotel and its components were modelled with the TRNSYS 17 simulation program. The climatic data were obtained through METEONORM, provided by TRNSYS and distributed under license from Meteotest.

For the building simulation in TRNSYS, the floors were divided in different sub-zones with similar characteristics of utilization. In total, 14 sub-zones were considered for the numerical simulation. For example, as can be seen in Figure 3, the ground floor (GF) was divided in 3 sub-zones: lounge (zone GF.1), rooms (zone GF.2) and reception (zone GF.3). The cave was divided in 3 sub-zones and each floor was divided in 2 sub-zones, corresponding to the east and west façades.

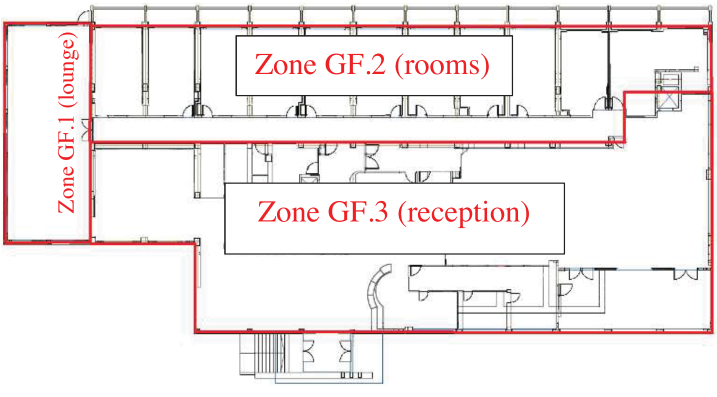

Fig. 3: Ground floor and sub-zones.

The building cooling and heating load, for an indoor air temperature thermostatic control of 25ºC and 20ºC, were calculated for the cooling and heating seasons, under climatic conditions of Tenerife. These temperatures were considered to maintain operative temperatures in the range proposed in ISO 7730 (between 20ºC and 26ºC for 1.2 met), within thermal comfort requirements. The study was extended throughout a whole year. Also, indoor temperatures were calculated through numerical simulations.

A multi-zone building model (TRNSYS type 56) was used. Besides the definition of geometry and materials, other input data considered were: infiltration rate of 1.2 air changes per hour, room internal gains corresponding to two persons per day in each room, artificial lighting of 5 W/m^2, TV, computers in the reception, different equipment in the kitchen, etc. The metabolic rate (heat production depending on action level) was assumed as

1.2 met (1 met = 58.2 W/m^2). This corresponds to seated and light activity at home, office, hotels, etc. (ISO 7730:2005).

Also, the installation of the photovoltaic collectors (PV) and thermal solar collectors (FPC) were analyzed through numerical simulation. Table 2 shows the FPC and PV modules characteristics used in the numerical simulation.

Tab. 2: Characteristics and technical data of the FPC and PV collectors.

FPC		**Constante Solar-Cu-1208-P**
Collector efficiency parameters related to aperture area:	η_0	0.79
	a_1	3.64 W/m^{2}K
	a_2	0.02 W/m^{2}K^2
Gross Area		2.63 m^2
PV panels		**TSM-300**
Nominal peak power*		300 Wp
Nominal voltage (Vmp)*		36.9 V
Nominal current (Imp)*		8.13 A
Nominal efficiency		15.5 %
Open-circuit voltage (Voc)*		41.3 V
Short-circuit current (Isc)*		2.02 A
Module area (A_{PV})		1.94 m^2
Cells		Multicrystalline

*STC: 1000W/m^2, AM 1.5, 25ºC.

4. Results

4.1. Analysis of hotel energy demand

For estimating the hotel energy demand, space heating and cooling requirements were determined for all sub-zones, according to the operating conditions presented in Section 3. Monthly incident solar radiation (total) on horizontal and vertical façades is shown in Fig. 4. The annual horizontal incident solar radiation is 1640 kWh/m^2.

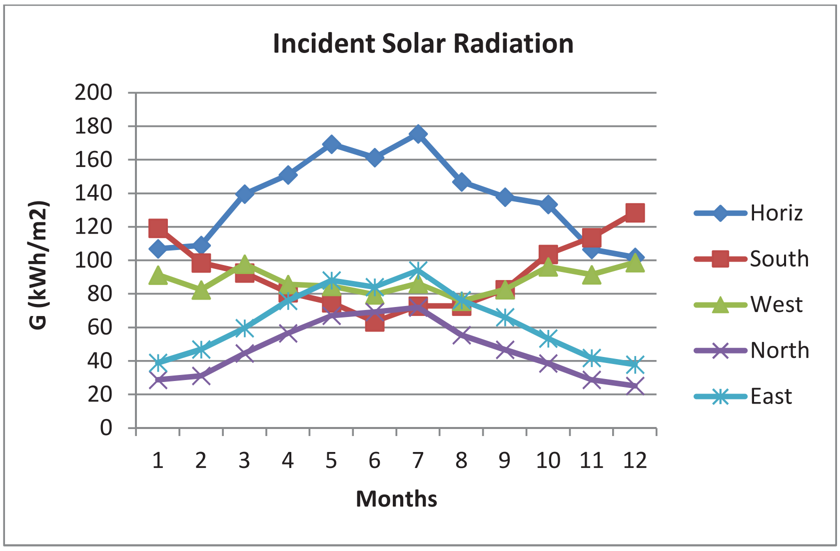

Fig. 4: Monthly incident solar radiation for horizontal and vertical façades.

Figure 5 and Figure 6 show the hourly simulated indoor air temperature without cooling or heating system, and the outdoor ambient temperature for 2 sub-zones (Ground Floor-reception and East sub-zone in Floor 3), during the 21st of July (when the incident solar radiation and the ambient temperature are very high) and 21st of December (when the incident solar radiation and the ambient temperature are lower). In these figures, no use of internal or external shading, such as blackout curtains or blinds, was considered.

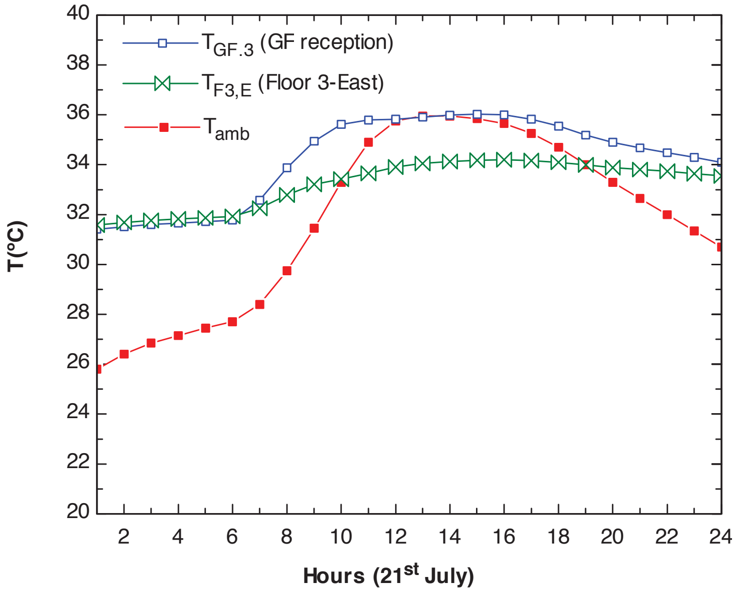

Fig. 5: Hourly indoor air temperature without cooling, and outdoor ambient temperature during 21st July.

Note that the indoor air temperature is higher than 25ºC during the July day, when the cooling system (Chiller/Heat Pump) is not used. Also, during the cooling season higher indoor air temperatures could be achieved in the different floors if solar passive strategies were not used; then, comfort conditions could almost never be reached in the hotel during this period.

A solar passive strategy adopted by the hotel employees is to close the interior blackout curtains during the day in the cooling season, after cleaning the rooms. This possibility was also studied in this work. When the interior curtains are closed during the day, the internal average temperature in the rooms decreases between 0.2 to 0.9ºC, depending on the floor.

When comparing the indoor air temperatures of the East and West sub-zones in each floor, it was possible to verify that the West sub-zones have a higher temperature than the East sub-zones (about 0.2ºC difference). It can be justified by the higher glazed area/façade area in the West façade, as seen in Table 1.

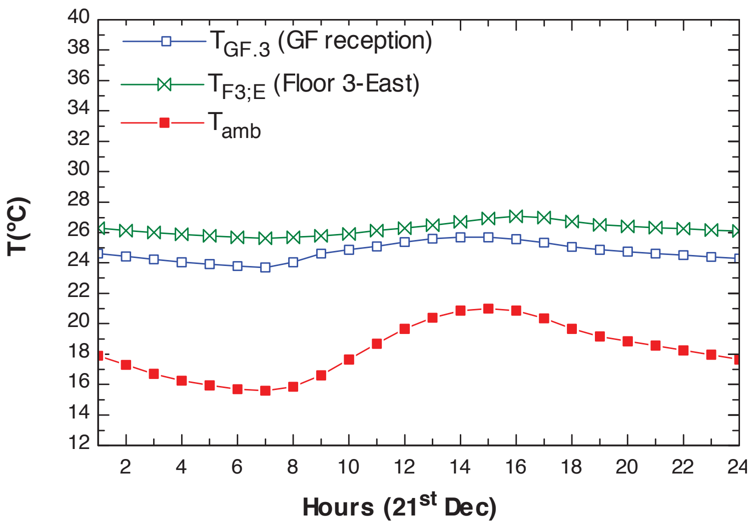

Fig. 6: Hourly indoor air temperature without cooling or heating, and outdoor ambient temperature during 21st December.

As can be seen in Figure 6, in a cold day in winter the outdoor temperature range is between 16 and 21ºC. If the indoor air temperature thermostatic control for the heating season is set for 20ºC, the heating system will be connected only a few hours during the year in the hotel. The usual guests of this hotel are foreign elderly persons in the winter time. For that, usually the air-conditioning with a thermostatic control of 24ºC is used in the rooms.

Table 3 shows the monthly and annual energy demand for heating and cooling with different thermostatic control set points. In the last row, the annual energy demand is divided by the net floor area of the hotel (5940 m^2).

Tab. 3: Monthly and annual energy demand for heating and cooling.

Month	Heating (MWh) ($T_{control}$=20ºC)	Heating (MWh) ($T_{control}$=24ºC)	Cooling (MWh) ($T_{control}$=25ºC)
January	0.08	10.33	2.31
February	0.08	6.03	3.97
March	0.01	2.88	10.81
April	0.00	0.87	14.67
May	0.00	0.27	26.41
June	0.00	0.00	38.67
July	0.00	0.00	63.79
August	0.00	0.00	62.13
September	0.00	0.00	52.90
October	0.00	0.00	45.48
November	0.00	0.37	19.69
December	0.00	2.19	9.58
Annual (MWh)	**0.18**	**22.95**	**350.42**
Annual (kWh/m^2)	**0.03 kWh/m^2**	**3.86 kWh/m^2**	**58.99 kWh/m^2**

Note that the energy demand for cooling is considerably higher than the energy demand for heating. These values are similar at hotels with similar climates as shown in the literature (Polanco and Yousif, 2015).
Using the Chiller/Heat Pump installed in the hotel ($COP_{heating}$ = 3.1 and $COP_{cooling}$ = 2.1), the annual electricity consumption in the hotel for air-conditioning is 7.4 MWh/year for heating and 167 MWh/year for cooling. Considering the energy consumed in 2015, see Figure 7, the air-conditioning represents about 30% of the electricity consumption of the hotel.

4.2. Actual hotel energy consumption

- <u>Domestic Hot Water (DHW)</u>

Considering the occupancy 138 guests per day during the year, and a water heating consumption of 60 l/guest, the annual energy consumed for hot water (HW) is about 160 MWh/year. Knowing that the useful energy from the solar thermal collectors (FPC) for water heating is 151 MWh/year, the utilization of the heat pump is also necessary for HW.
On the other hand, the useful energy from the other solar collectors used for swimming-pool heating, may not be enough for the whole year. For that, the utilization of the boiler should be considered.

- <u>Energy consumption (electricity, propane and diesel)</u>

The energy consumed in the hotel from non-renewable energy sources is shown in Figure 7. These values were obtained from the invoices delivered by the hotel staff.

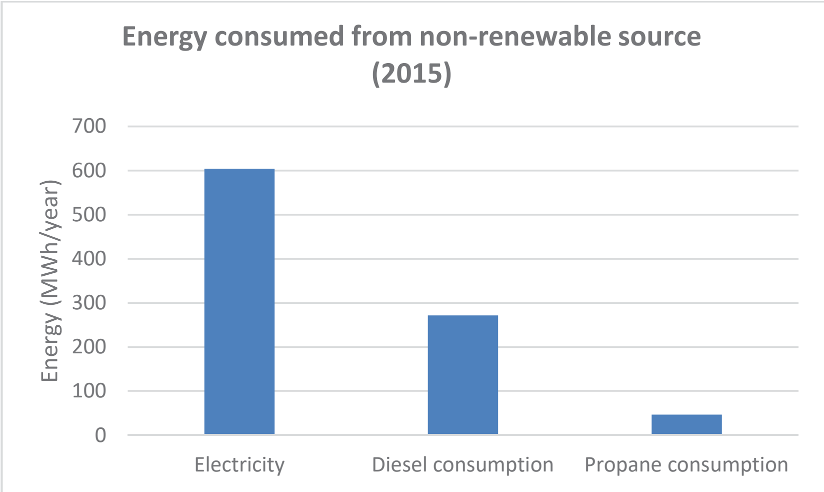

Fig. 7: Main hotel consumptions from non-renewable sources during the year 2015.

Figure 7 shows the energy consumed in the hotel without considering the contribution from the FPC installed on the roof. In this distribution, electricity represents 66%, diesel 29% and propane 5% of the total consumption. Note that diesel is used in the boiler and propane is only used for the kitchen equipment. When the contribution of FPC is considered (151 MWh/year) these percentages change, as can be seen in Figure 8. The annual energy consumption from non-renewable sources was 1073 MWh/year for the year 2015.

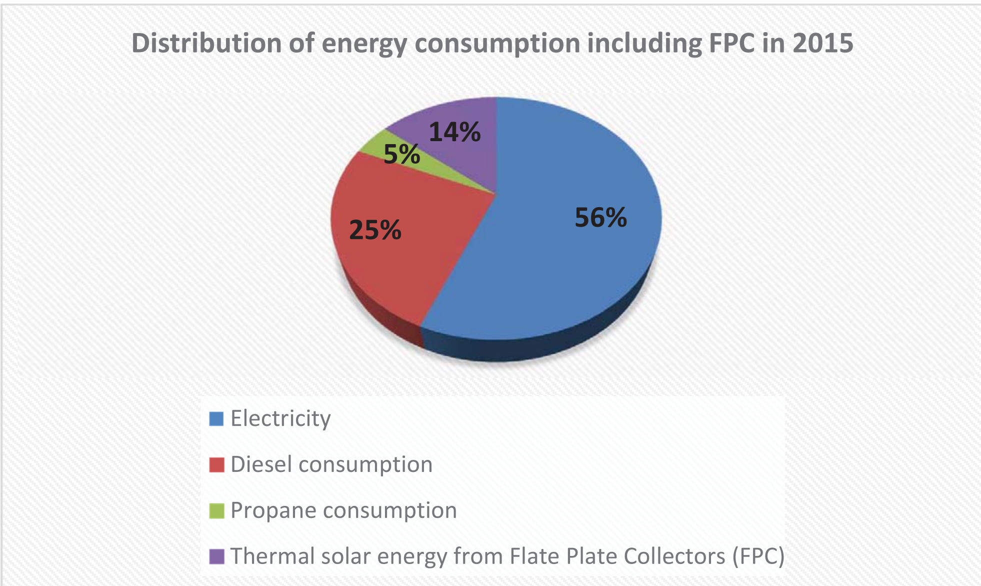

Fig. 8: Main hotel consumption from non-renewable and renewable sources during the year 2015.

After analyzing the annual energy consumption of the hotel, different options using renewable energy should be considered. The next section analysis the different options proposed in this work to achieve the nZEB for the hotel.

4.3. Energy consumption using renewable sources

Figure 8 demonstrates that electricity represents the most important energy consumption in the hotel. For that, the utilization of photovoltaic collectors (PV) is proposed. After analyzing the available space in the hotel to place photovoltaic collectors, two places were chosen: the car park and a nearby parking area. The number of panels to install will be 355 modules with a total aperture area of 689 m^2, and the electricity production was obtained

At the same time, it is possible to increase the number of solar thermal collectors on the roof of the hotel. Thus, using the same type of collectors, the useful area will increase 30 m^2 (from 117 m^2 to 147 m^2) and the annual heating useful energy will increase from 151 MWh/year to 189 MWh/year.

Table 4 shows the hotel energy consumption in 2015 and the expected energy consumption with the referred PV and FPC collectors' implementation in the hotel.

Tab. 4: Annual energy consumption using PV and FPC collectors.

		Energy consumed in 2015 (MWh)	Energy consumed improved with Renewable Sources (MWh)
Non-renewable sources	Electricity from grid	604	426
	Diesel consumption	271	233
	Propane consumption	47	47
Renewable sources	Thermal energy from FPC	151	189
	Electricity from PV	0	178
Total energy consumption		1073	1073

Figure 9 shows the annual distribution of the energy consumption considering the data of 2015, using FPC and PV. As can be seen, it is possible to achieve a total of 34% of the consumed energy with renewable energies (18% from FPC and 16% from PV).

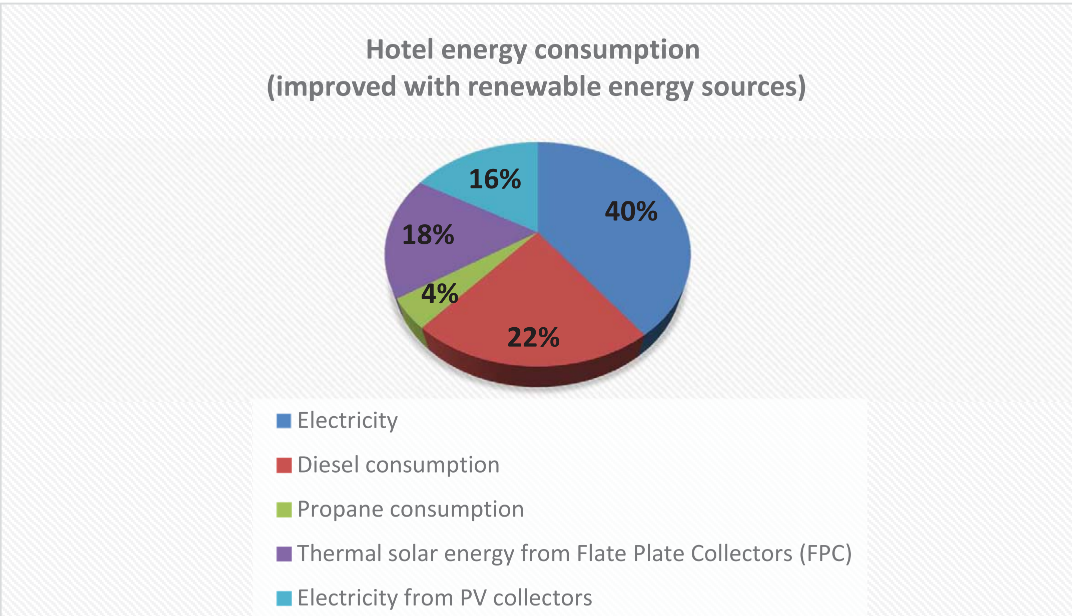

Fig. 9: Annual energy consumption distribution using renewable systems.

Using the definition of nZEB explained in the Introduction (Section 1), with the results obtained through the utilization of solar collectors, the target of nZEB for this hotel is still not achieved.

On the other hand, the diesel consumption used in the hotel is very high due to the utilization of the boiler during a long period. This boiler is used especially for water heating in HW and swimming-pool. We can propose to replace the actual diesel boiler by a biomass boiler. Biomass is considered a renewable source and it could be a good solution to reduce fossil fuel consumption. In Canary Island, the utilization of biomass boilers in hotels is starting and it has shown a promising future (Arlangton comp., 2016).

If a biomass boiler is used in this hotel for water heating, the diesel consumption will be null. In this case, it is possible to achieve 56% of the energy consumption with renewable energies (18% from FPC, 16% from PV and 22% from biomass).

5. Conclusions

In this work, the energetic analysis of a hotel located in Tenerife was performed and the implementation of different renewable energy systems was proposed.

During the cooling season it was demonstrated that higher indoor air temperatures could be achieved in the different floors, if the chiller or solar passive strategies were not used. The annual energy demand for cooling, to maintain the indoor air temperature below 25ºC, is about 350 MWh/year (58.99 kWh/m^2). When shading devices are considered, the indoor air temperature decreases between 0.2 to 0.9ºC, depending on the floor. Using the Chiller/Heat Pump installed in the hotel, the annual electricity consumption for air-conditioning is 7.4 MWh/year for heating and 167 MWh/year for cooling. Then, air-conditioning represents about 30% of the hotel electricity consumption.

After analyzing the annual energy consumption, different options using renewable energy (FPC and PV) were considered. It was demonstrated that it is possible to achieve 34% of the consumed energy with renewable energies (18% from FPC and 16% from PV). On the other hand, the diesel consumption is high because of the use of the boiler for water heating. If the actual diesel boiler is replaced by a biomass boiler, it is possible to achieve 56% of the consumed energy with renewable energies (18% from FPC, 16% from PV and 22% from biomass).

With the results obtained through the utilization of solar collectors and biomass, the target of nZEB is still not achieved for this hotel. Anyway, with the proposed improvements, the energy consumption using renewable sources would increase 4 times, from 14% to 56%.

Acknowledgments

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