Energy use in hotels: a case study in Gran Canaria

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Abstract

In this paper, the energy models of six hotels were compared. Food and beverage (F&B) service demands the highest amount of energy (over 50%), followed by the hot water system. A regression analysis revealed that, among 31 different characteristics, the revenue per available room, the pool volume, the number of diners and the mean number of guests per occupied room can explain the total energy demand of the studied hotels. The possibility of including photovoltaic solar energy could increase the renewable contribution of the energy mix by 8–30%, but this highly depends on the available surface for this installation in each hotel.

Keywords: environmental performance; hotel sector; energy consumption; Canary Islands; energy optimization

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1. INTRODUCTION

The hospitality industry is an important source of income in many places. Spain was the most common outbound tourism destination in the EU in 2018, for people traveling outside their country, with 23% of the EU total [1]. In Spain, tourism represented 12.3% GDP and 12.7% total employment in 2018 [2]. Among the destinations, the Balearic and Canary Islands are preferred by tourists. In the particular case of the Canary Islands, tourism represented 35.0% GDP and 40.4% employment in 2018 [3]. In this sense, in 2019, the population in the Canary Islands was 2 153 389 and the equivalent tourist population was 281 344 (11.6% of the total population) [4]. Regarding electricity consumption, between 12.8% and 16.5% of the total electricity produced in the archipelago between 2014 and 2017 was destinated to the tourist sector [5].

To provide comfort to the guests, hotels need to use several resources, including energy. It is known that electricity consumption is the dominant source of carbon emission in this sector [6]. On many occasions, these energy requirements are not optimized and thus contribute to a high carbon footprint. Carbon emissions per occupied room have been reported from 7.2 $kgCO_2$-e up to 199.1 $kgCO_2$-e, depending on the destination. In Spain, emissions are typically between 7.2 and 45.58 $kgCO_2$-e [7].

Regarding Directive 2010/31/EU, buildings account for 40% of the total energy consumption in the European Union and is bound to increase. For this reason, the reduction of energy consumption and the use of renewable sources in buildings have been legislated. In addition, Directive 27/2012/EU promotes energy efficiency targets that include energy audits of buildings. However, in 2007, at least 70% of the buildings in Spain were built before 1980, that is, to say that their constructive characteristics predate the above-mentioned regulatory requirements [8].

In addition, although several studies suggest renewable options for the Canary Islands [9–12], only 7.8%, 11.8% and 15.5% of the total energy was produce by renewable sources in 2017, 2018 and 2019, respectively [13]. According to the potential (mainly wind and solar energy), the renewable sources should be promoted in the next years.

On the other hand, surveys indicate that in 2016, 51% of the hotels all around the world were following official sustainability criteria from recognized organizations [14]. Travelife is one of the most known environmentally friendly certifications in hospitality. Currently, only 10% of the hotels in the Canary Islands are certified in Travelife [15]. In addition, in Spain, only 159 hotels are certified in ISO 14001 [16]. A recent study reveals that the sustainability policies of hotels in the Canary Islands can be improved, especially in the social dimension [17]. In this sense, a survey carried out in Gran Canaria in 2016 revealed that 49.8% of the 1069 respondents considered that the accommodations should be more respectful with the environment [18]. On the other hand, Puig *et al.* [19] concluded in a previous study that the

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Table 1. *Detail of electricity and gas consumption monitoring.*

Hotel no.	Data source	Monitored sector	Period
1	Network analyzer	Rooms	30 September 2019 to 08 October 2019
1	Network analyzer	Poolbar	16 September 2019 to 18 September 2019
1	Network analyzer	Kitchen	18 September 2019 to 23 September 2019
1	Electricity meter	Spa	1 August 2019 to 31 August 2019
1	Network analyzer	Machinery	23 September 2019 to 27 September 2019
1	Network analyzer	Common area lighting	27 September 2019 to 30 September 2019

implementation of environmental monitoring systems promotes the collection of data and helps in a more efficient use of resources.

It must be mentioned that the Canary Islands destination has a high environmental interest. Thus, the islands of Lanzarote, Tenerife (Arona) and La Palma are members of the Biosphere Destinations Community. In addition, the islands of La Palma (1983), Lanzarote (1993), El Hierro (2000), 46% of Gran Canaria (2005), Fuerteventura (2009), La Gomera (2012) and the area of Macizo de Anaga in Tenerife (2015) are recognized as biosphere reserves by UNESCO [20].

In this study, we collaborated with a hotel company with a base in Gran Canaria that provided data from six different hotels and apartments with different energy supply models. Real-time energy demand data are included for one hotel.

The aim of this study was to analyze the energy production model in the different hotels of Gran Canaria to determine the areas where actions can lead to a more sustainable system and predict energy consumption beforehand, based on other indicators. We consider this study of special interest for the Canary Islands due to the impact that hospitality has on the energy consumption of the Islands and the needs for this sector to move to more sustainable methods, considering the environmental interest of the area and the opinion of tourists.

2. MATERIALS AND METHODS

A detailed energy analysis was carried out in one hotel and energy data were collected in another five hotels. All the hotels that collaborated in this work belong to the same company and are located in Gran Canaria.

The general procedure for energy auditing was used. That is, first, we collected data from the buildings and the energy systems in each one. Next, we took data from the installed electricity, water and gas meters and from the electricity and gas bills. Data for fuel consumption were given in kilogram and converted to kilojoule using the heat capacity of the fuel. Conversion to kilowatt-hour was done knowing that 1 kWh equals 3600 kJ. Finally, we used a network analyzer, Metrel MI 2092, with a 4-W connection in one hotel to monitor the electricity demand in 5-minute intervals in different electric panels.

The study was carried out in two periods: summer 2019 (from 01 May 2019 to 31 October 2019) and winter 2019/20 (from 01 November 2019 to 30 April 2020). It must be noted that the hotels closed temporarily on 20–22 March 2020 due to the sanitary COVID-19 crisis.

The specific electricity meters monitored and the electric panels monitored with the network analyzer are detailed in Table 1. The measures with the network analyzer were carried out in the summer 2019.

3. RESULTS AND DISCUSSION

3.1. Building characteristics

The hotels that participated in this study, the services offered and the energy systems installed in each one of them are detailed in Table 2. The data given for the number of workers, average daily rate (ADR), occupancy, revenue per available room (RevPar) and global review index (GRI™) are the mean annual values, and the number of clients and diners, number and cost of repairs, number of led bulbs changed, reposition of refrigerants, amount of recycled waste and water consumption are the total annual values.

It should be noted that all buildings were constructed in the 1980s and, regarding the original energy installations, only Hotels 1, 5 and 6 have been updated in recent years. Hotels 3 and 4 have been partially updated and Hotel 4 is expected to be totally refurbished in 2021.

Hotels 1 and 5 are 4-stars, Hotels 3, 4 and 6 are 3-stars and Hotel 2 is 2-star. Attending to capacity, Hotel 5 has the highest number of beds, followed by Hotels 4, 3, 6, 2 and 1. The gross floor area (GFA) of each building follows the same order than the hotel capacity. Pool areas are also higher for the larger hotels. Regarding the number of pools, Hotels 1, 4, 5 and 6 have more than one pool. Generally, the second pool is a Jacuzzi type, with climatization at 30–35°C.

Currently, the hot water systems are mainly based on heat pumps for pools and boilers or electric thermos (Hotels 2 and 3) to produce the remaining hot water. Heating, ventilating and air conditioning (HVAC) systems are used in Hotels 4 and 5 as a complement to propane boilers. Only Hotels 1 and 6 include renewable sources for hot water production. The source for electricity is external in all hotels except for number 3, where a solar photovoltaic installation was included recently. Water consumption is, in general, higher for the hotels with a larger capacity. The hotel with lower annual water consumption is Hotel 2, which is the one that offers a smaller or more limited number of services (no F&B, only one pool and no spa).

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Table 2. *Hotels and services.*

Hotel no.	Star	No. of rooms	No. of beds	No. of floors	Last retrofit (years)	GFA (m^2)	Pools (m^3)	Pools (m^2)	Aircon	Spa	Kitchenette in room	Travelife certified	Hot water system	
													Rooms	Pools
1	****	97	194	8	7	3771	115 (24°C) 43.3 (35°C)	153.58	Split	Yes	1	1	Solar (backup: gasoil boiler)	Heat pump
2	**	113	226	8	32	5284	205.2 (24°C)	174.20	No	No	1	0	Electric thermos	Heat pump
3	***	306	612	21	36	13725	1028.5 (24°C)	862.42	Split	No	1	0	Electric thermos	Heat pump
4	***	350	700	4	30	21310	605 (cold) 486 (24°C) 23 (30°C)	850.36	Split (85 rooms)	No	1	0	Boiler (propane) and HVAC	Heat pump and boiler (propane)
5	****	511	1022	7	6	25316	711.9 (24°C) 45.7 (35°C)	1004.62	Central (propane)	No	0	1	Boiler (propane) and HVAC	
6	***	232	464	8	40	8884	406.9 (24°C) 1.2 (35°C)	311.68	No	No	1	1	Solar thermodynamic (backup: propane boiler)	

Table 2. *(continued). Hotels and services.*

Hotel no.	**Star**	**Electricity source**	**F&B***	**ADR (€)**	**Occupancy (%)**	**RevPar (€)**	**GRI™**	**No. of workers**	**No. of pax**	**No. of adult guests**	**No. of children's guests**
1	****	External supply	HB and SK	98.38	83.94	82.33	87.40	48	58 329	58 331	0
2	**	External supply	SC	47.60	74.99	38.77	80.27	15	65 110	62 788	2418
3	***	Solar and external supply	BB and SK	65.47	82.33	53.41	86.06	49	197 887	178 693	21 183
4	***	External supply	AI	111.71	81.83	91.84	81.78	116	258 476	219 676	42 984
5	****	External supply	AI	99.02	83.69	82.51	84.15	223	358 979	312 136	53 634
6	***	External supply	HB and SK	73.34	81.08	59.28	83.74	63	139 720	133 987	6653

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Table 2. *(continued). Hotels and services.*

Hotel no.	Star	No. of diners	Mean no. of guests per room	No. of repairs	No. of led-lights	Cost of repairs* (€)	Water consumption (m^3)	Refrigerant reposition (kg)	Recycled kitchen oil (kg)	Recycled cardboard (kg)
1	****	52 182	1.93	3354	324	152 382.87	15 791	2	1350	5080
2	**	0	2.06	1657	460	649 937.08	11 530	0	0	0
3	***	16 449	2.10	6303	740	338 121.02	41 754	18.6	460	0
4	***	257 730	2.42	7418	618	261 237.41	59 543	44.5	3280	11 880
5	****	354 526	2.25	10 842	916	616 215.45	71 484	12	6990	30 880
6	***	53 867	1.99	2268	447	308 687.06	25 111	2	630	6260

*Referred to the cost of the necessary materials for repairs.

The rooms in all buildings except for Hotel 5 have an electric kitchenette. In addition, 70 and 16 rooms in Buildings 1 and 3, respectively, have a hydrothermal bathtub. Laundry is outsourced, although there are two to three washing machines (capacity of 15 kg each) and driers (capacity of 15 kg each) in each hotel to wash some elements such as curtains, cushions, etc.

Regarding F&B services, Hotels 4 and 5 are all-inclusive, Hotels 1, 3 and 6 offer certain meals and Hotel 2 is self-catering. Hotels 3, 4 and 5 are preferred by families with children, and, therefore, the mean number of guests per room is higher than 2 in these hotels. On the contrary, Hotel 1 is only-adults and has a small Wellness Centre with spa, which is offered for free to their guests.

Regarding air-conditioning, only Hotel 5 is centrally air-conditioned. Split units are used in Hotels 1 and 3 and in some rooms in Hotel 4, and no air-conditioning is included in Hotels 2 and 6.

For the studied period, the number of repairs was, in general, higher for larger hotels. However, Hotel 1 presented a higher number of annual repairs than Hotel 6 (which is larger). This may be due to a greater number of installations in Hotel 1 (bathtubs in rooms, spa). It must also be noted that the cost of repairs did not follow the same trend than the number of repairs. In this sense, Hotel 2 had the lower number of repairs and the highest cost; this suggests that the magnitude of repairs depends on the state of the installations.

ADR was highest for all-inclusive hotels, followed by those with some F&B services. The mean annual occupancy was over 80% in all hotels except for Hotel 2, where it was ~75%. Quality indicators are GRI™ and Travelife certification. GRI™ is a measure of customer rating and was above 80% for all hotels. Three hotels were Travelife certified: Hotels 1, 5 and 6. Recycling of kitchen oil and carboard was greater for those hotels with more intensive F&B service, that is, half-board or all-inclusive.

3.2. Energy consumption

Figure 1 shows the total energy consumption for each establishment and the consumption per overnight stay (pax). The reference unit chosen for analysis was pax, which is the most employed reference unit in hospitality.

Energy consumption varied significantly between the different hotels and was higher in the summer months in Hotels 3–5. Per pax, energy consumption remained almost constant throughout the year, except in Hotel 2, where it was clearly higher in the winter season. This may be because the energy consumption in this hotel was mainly due to water heating, as no F&B service or air-conditioning was included among the offered services. The cold water temperature in this location was 16.8 ± 0.9°C in summer and 14.5 ± 1.1°C in winter. Thus, the thermal jump to produce hot water and to heat the pool was lower in summer. This effect can also be slightly seen in Hotel 5 and clearly seen in Hotel 6. It must be noted that Hotel 6 closes the main restaurant in the summer months (only the pool bar is left open).

Hotel 2 was closed on May 2019. Additionally, all hotels were closed on 23 March 2020 due to the COVID-19 sanitary crisis, and

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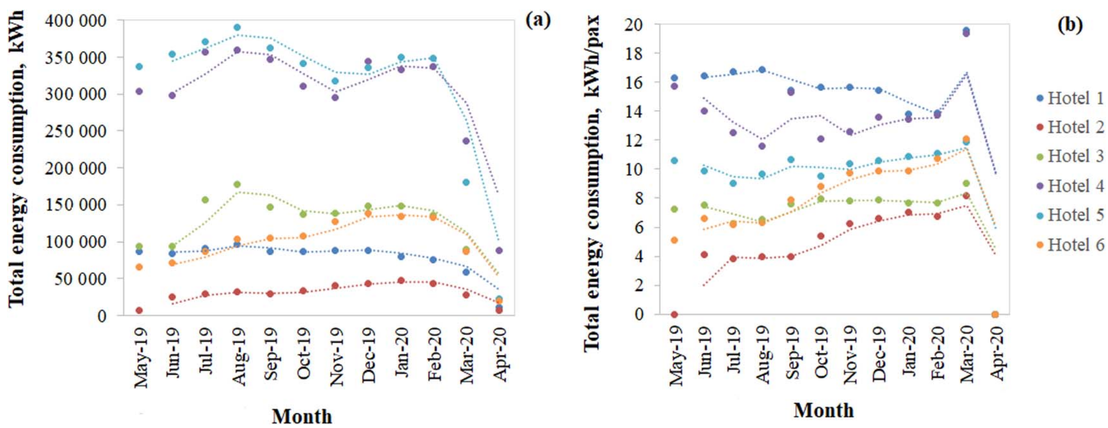

Figure 1. *(a) Energy consumption and (b) energy consumption per pax.*

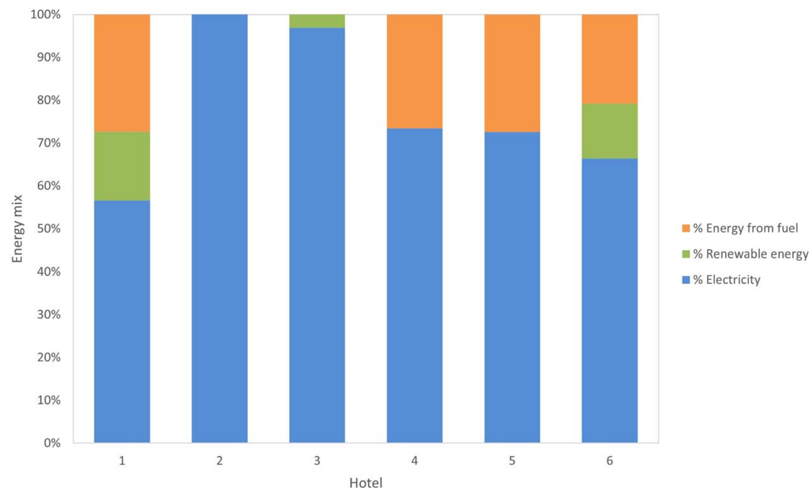

Figure 2. *Energy mix for the different hotels.*

for this reason, energy consumption falls to almost cero in April 2020.

Hotel 2 had the lower consumption (annual mean 5.61 kWh/-pax), followed by Hotels 3 and 6 (annual means 7.57 and 7.33 kWh/pax, respectively), Hotel 5 (annual mean 10.40 kWh/-pax) and Hotels 1 and 4 (annual means 13.37 and 14.01 kWh/pax, respectively). The differences in energy requirements can mainly be attributed to the services offered in each hotel. In this sense, Hotel 2 did not offer air conditioning or F&B, and this is the reason why energy consumption was much lower here than in Hotel 1, where these services were included, and we could also find a spa. On the other hand, Hotels 4 and 5 provided similar services but the energy requirements were higher in Hotel 4. As was mentioned before, this hotel is expected to be totally refurbished in 2021 and both solar thermal and photovoltaic energy have been projected.

Data for energy consumption in April 2020, when hotels were closed due to COVID-19 sanitary crisis, show that the mean minimal energy requirements represented between 9% and 36% of the requirement when hotels were open and almost fully booked. These wide differences depend on the minimun installations that were kept working during closure. For example, in Hotel 4, all freezing chambers were kept working. In addition, the larger pools were kept working in all hotels during closure, although unheated.

Regarding energy mix, Figure 2 includes the mean annual percentage of electricity and fuels used in each hotel. The percentage of renewable energy is also included. Between 55% and 70% of electricity was employed in most hotels, except for Hotels 2 and 3 where 100% and 96,95% of the energy, respectively, came from electricity. Thus, electricity was the primary energy source, which was used for lighting, refrigeration chambers and most of the machinery. Results are slightly lower than those reported by other authors between 2002 and 2021, which concluded that between 60% and 80% of the total energy consumed by hotels in Hong Kong, Singapore, USA and Italy came from electricity [21–24]. This indicates the importance of investing in renewable energy for electricity production in hotels to reduce both environmental impacts and energy costs.

Gas was mainly used for cooking, although it was also used in the central air-conditioning system in Hotel 5 and for hot water in

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Hotels 4–6. Additionally, a gasoil boiler was employed as backup in Hotel 1 for hot water. Gasoil was also employed for stand-by electricity generation but the consumption for this purpose was negligible.

In Hotel 3, a solar photovoltaic installation provided 4% of the total energy consumption during the studied period (May 2019 to April 2020). In Hotels 1 and 6, renewable sources provided energy for hot water, accounting this for 12–16% of the total energy requirement.

The percentage that came from the solar renewable source in Hotel 3 was calculated from an electricity meter installed in the hotel to monitor the photovoltaic plant production. For the calculation of the renewable contribution in Hotels 1 and 6, data from water meters at the solar installations and water temperature measures were used. Equation (1) was employed to convert these data to energy units.

$$Q = mc_p\Delta T, \tag{1}$$

where Q is the amount of heat (kJ), m is the mass of water (kg), c_p is the specific heat capacity of water (kJ/kg°C) and ΔT is the temperature difference between hot and cold water (°C).

3.3. Relations between energy consumption and hotel's characteristics

Several authors have analyzed the relation between energy consumption and several factors or characteristics, such as hotel star rating, number of occupied rooms, number of workers, outdoor temperature, building age, etc. These relations are important because an appropriate analysis can lead to high energy savings. Cabello Eras *et al.* [25] implemented energy performance indicators in two hotels in Cuba in 2014 and achieved ~10% energy savings in 1 year. Tsoutsos *et al.* [26] calculated in 2017 that the refurbishment of a hotel in Greece by adding double glazed windows, photovoltaic modules, solar collectors and heat pumps for hot water could save up to ~60% energy.

Lai [6] found in 2014 that carbon emissions in three hotels in Hong Kong returned a strong positive correlation with outdoor air temperature but not with occupancy rates. A previous study developed in 2002 by Shiming and Burnett [22] reported that outdoor air temperature is about four times more significant than the number of guests for electricity consumption. Papageorgiou *et al.* studied energy management in hotels in Cyprus (2018) and found that outdoor air temperature influences in energy consumption. However, they also reported that electricity consumption is exponentially dependent on the average number of guests per month [27]. Pablo-Romero *et al.* studied electricity consumption in the hospitality sector in 12 Spanish Mediterranean provinces in 1999–2014 and found a growing relationship between electricity consumption and overnight stays, specially in hotels with high-star ratings; they also found non-linear positive correlation between electricity consumption and outside temperature (expressed as CDD and HDD). Meschede *et al.* [28] reported in 2017 that electricity demand in a hotel in La Gomera (Canary Islands) depends on ambient temperature but not on occupancy; they suggested that the lack of correlation between electricity consumption and occupancy was due to several occupancy-independent electricity consumers such as lighting, kitchen or offices. As can be seen, all authors agree that outdoor temperature influences on energy consumption but discrepancies are found for the relation between energy consumption and occupancy.

Although less frequent, some other authors analyzed other factors additionally to outdoor air temperature and occupancy. For example, Bohdanowicz and Martinac [29] analyzed in 2006 the energy and water consumption of 184 European hotels belonging to the same hotel chain and found significant positive correlation between the energy consumption and the total hotel floor area, overnight stays, number of meals, amount of laundry washed onsite and presence of a health club in the hotel. Another study carried out in Taiwan in year 2010 found correlation between energy consumption and the number of rooms, GFA, room rate, occupancy and total revenue [30]. Borowski and Zwolinska [31] developed models for cooling energy prediction in a hotel in Poland and found clear impacts on energy consumption due to relative humidity, máximum wind speed, ocuppancy, hour and day of the week.

In this work, we calculated Pearson correlations of energy demand with 31 different variables and characteristics of the hotels. Results are shown in Table 3.

The correlation coefficient is interpreted as follows: negligible correlation is considered for values below 0.29; low correlation, for values between 0.3 and 0.49; moderate correlation, for values from 0.5 to 0.69; high correlation, for values between 0.7 and 0.89; and very high correlation, for values above 0.9 [32].

From our results, energy consumption depended to a large extent of overnight stays and number of diners. The number of workers and rooms in the hotel also showed a high correlation with energy consumption. However, occupancy, which was calculated as the percentage of occupied rooms over the total, had low correlation with energy consumption. This indicates that more energy was consumed when more people (guests and workers) were using the hotel facilities. The lower correlation between energy consumption and occupancy may be because in most hotels there are family rooms and, thus, the mean number of clients per occupied room is different for the different hotels and, among the same building, for different months. In this sense, a moderate correlation was observed between energy consumption and the monthly mean number of guests per room.

In addition, a moderate positive significant correlation was found in ADR and RevPar and energy consumption, but low correlation was seen for star-rating and negligible correlation was returned for quality indicators such as GRI™. The lack of correlation indicates that all hotels operate on a similar energy model, despite the star-rating or opinion of clients.

Regarding the building's characteristics, the number of rooms, GFA and pool area and volume were moderate–highly correlated with energy consumption. However, in our study, the number of

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Table 3. *Pearson correlations between total energy demand and different variables.*

Variable	Pearson's r	Significant at the 0.05 level
Cold water temperature	-0.332	Yes
Star-rating	0.397	Yes
No. of rooms	0.794	Yes
No. of floors	-0.291	Yes
Years from last retrofit	-0.290	No
GFA	0.854	Yes
Pools (volume)	0.650	Yes
Pools (area)	0.754	Yes
Pools (temperature)	-0.399	Yes
Aircon	0.526	Yes
Spa	-0.289	Yes
Kitchenette in room	-0.559	Yes
Travelife certified	0.041	No
Renewable energy (kWh)	-0.267	Yes
No. of meals served per day	0.869	Yes
ADR	0.607	Yes
Occupancy	0.392	Yes
Mean no. of guests per room	0.535	Yes
RevPar	0.635	Yes
GRI™	-0.153	No
No. of workers	0.794	Yes
No. of pax	0.921	Yes
No. of adult guests	0.913	Yes
No. of children's guests	0.814	Yes
No. of diners	0.947	Yes
No. of repairs	0.872	Yes
Cost of repairs	0.676	Yes
Water consumption	0.940	Yes
Refrigerants reposition	0.405	Yes
Recycled kitchen oil	0.839	Yes
Recycled cardboard	0.812	Yes

floors and the years since the last retrofit showed small correlation with energy consumption, although the number of floors was significant. According the 'nearly Zero Energy Hotels' initiative, the primary energy indicator in Spain is 72 kWh/m^2/year for new hotels and 94 kWh/m^2/year for refurbished ones [26]. Cunha and Oliveira [33] reported that in a European perspective, the average energy consumption in hotels varies between 240 and 300 kWh/m^{2}year. The average energy consumption for the hotels in this study varied from 69.32 kWh/m^{2}year for Hotel 2 to 247.91 kWh/m^{2}year for Hotel 1. The rest of the hotels consumed between 108.58 and 169.35 kWh/m^{2}year. It must be noted that Hotel 2 is the one that provides less services.

Among the services offered, other authors have reported that certain services, such as a spa, do not influence energy consumption [29]. In this study, we cannot evaluate this rigorously because only one of the six hotels has a small spa.

The number of meals served per day was significantly correlated with energy consumption. In general, all the variables related with the F&B services were strongly and significantly correlated with energy consumption. The mentioned variables are number of diners, number of meals, recycled kitchen oil and recycled cardboard.

It must be noted that the amount of renewable energy returned a low Pearson's r when correlated with total energy consumption. This indicates that the dimensioning of these installations might need to be revised because they may be insufficient. For instance, in Hotel 1, bathtubs were installed in 56 rooms 4 years after the solar panels for hot water were installed: the addition of hot water consuming elements with no renovation of the solar installation may cause a bad correlation between renewable energy and total energy consumption. In Hotel 6, at the time of this study, 25% of the thermodynamic solar panels were not working due to maintenance. Lastly, in Hotel 3, the solar photovoltaic installation was mounted in September 2019; thus, it was only working during 66% of the evaluated period.

Moderate–high significant correlation was found between energy consumption and the number of repairs or the cost of repairs. More repairs will be necessary in bigger and not well-maintained hotels. Therefore, this suggests that building wear can influence energy demand. Our results differ from those reported previously, where no association was found between the maintenance costs of repairs and energy consumption [34]. Lastly, water consumption is also strongly related to energy consumption.

A multiple variable regression analysis was performed to develop a consumption prediction model. Initially, the 31 variables shown in Table 3 were included and next the model was refined by removing those variables that were statistically insignificant (at 95% confidence level). The final regression equation was the following.

Energy demand (kWh) = −45 494 + 405.43 RevPar + 6.768 D + 94.702 Pv + 23 551 PR, where D is the number of diners, Pv is the total pool volume (in m^3) and PR is the mean number of guests per occupied room. The unit of RevPar is €. The adjusted R^2 was 0.983. The residual plots are shown in Figure 3.

The regression model was next validated with monthly data from a different period, namely a previous year, from May 2018 until April 2019. The real versus predicted values are shown in Figure 4. Most values lie between ±10% and only 19.4% of the observations lie out of this range.

3.4. Energy consumption by end-use

In this paper, a deeper analysis of Hotel 1 was carried out. This hotel was chosen because it is the one with the highest energy requirements per gross surface area and per pax. Figure 5 includes the real-time electricity demand in the different areas of the hotel, and Figure 6 shows the energy demand by end-use.

The demand in rooms was low (3.31% according to Figure 6) and depended on the client's habits. In Figure 5a, data are shown for six rooms for three consecutive days, and, in general, higher demands occured between 10:00 and 12:00, and 16:00 and 23:00. It must be noted that the mini fridges in the rooms were connected to the kitchen electric panel, and, thus, the electricity consumption of this equipment are included as part of Figure 5c.

Figure 5b and c includes the demand in F&B areas. This consumption included the freezing and refrigeration chambers, which worked 24 hours and thus accounted for the minimun

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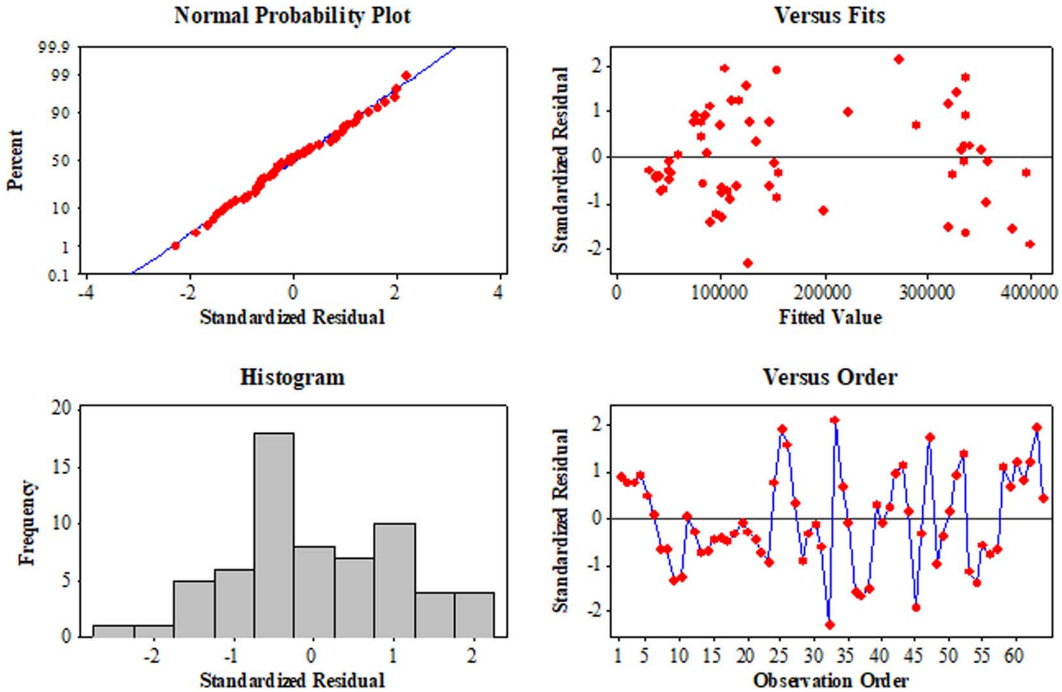

Figure 3. *Residual plots of the regression for energy consumption.*

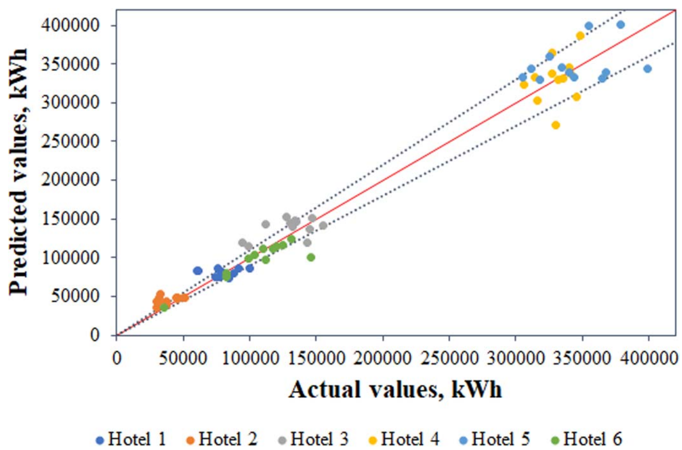

Figure 4. *Real versus predicted energy consumption.*

energy consumption in these areas, which is ∼3.5 kWh (∼50% of the total consumption observed in these areas). As mentioned above, this consumption includes the mini fridges in rooms, which account for ∼1.2 kWh (constant consumption). In total, F&B accounted for over 50% of the total energy requirements (Figure 6).

F&B services were as follow. The hotel served breakfast (buffet) from 7:30 until 10:30 and dinner (a la carte) from 18:00 until 22:00. Additionally, the pool bar was open from 12:00 until 18:00 and snacks were served from 12:00 until 16:00. The chill out (only for drinks) was open until midnight. This hotel had a daily mean of 166 ± 44 clients at breakfast and 22 ± 8 clients at dinner. The restaurant and pool bar were situated in the same place and lighting was shared. In addition, the show cooking area was connected to the pool bar electricity counter.

It can be seen from Figure 5b (pool bar) that consumption increased at 7:30, when breakfast started, and it started to decrease around 20:00–22:00. In the kitchen (Figure 5c), consumption increased earlier, at 6:30, that is, when the breakfast was being prepared, and it decreased around 23:00, after dinner. The higher consumption observed in the kitchen at 11:00 h was probably due to the dishwashing train.

An almost constant consumption was observed for the opening hours. To optimize this consumption, a detailed study of the operating proceedings in the kitchen must be carried out, together with an analysis of the equipment.

Regarding the spa (Figure 5d), the consumption varied between 150 and 350 kWh per day, accounting for ∼7.66% of the total energy demand (Figure 6). The spa contained a pool with 43.3 m^3 at 35°C, several jets that must be actioned by the client, two bithermic showers, a sauna and a Turkish bath. The pool was heated with a heat pump. If space were available, a more efficient way of heating the pool could be provided with an extension of the solar energy installation. In addition, a revision and optimization of the thermal insulation of the building could save up to 50% of the energy [35]. In this sense, the Spanish legislation (*Technical Building Code*) establishes the minimum insulation for buildings, but higher insulation would lead to higher energy savings. Following this, although the spa in this hotel does not have a high window area, the use of smart windows could also contribute to energy efficiency [36].

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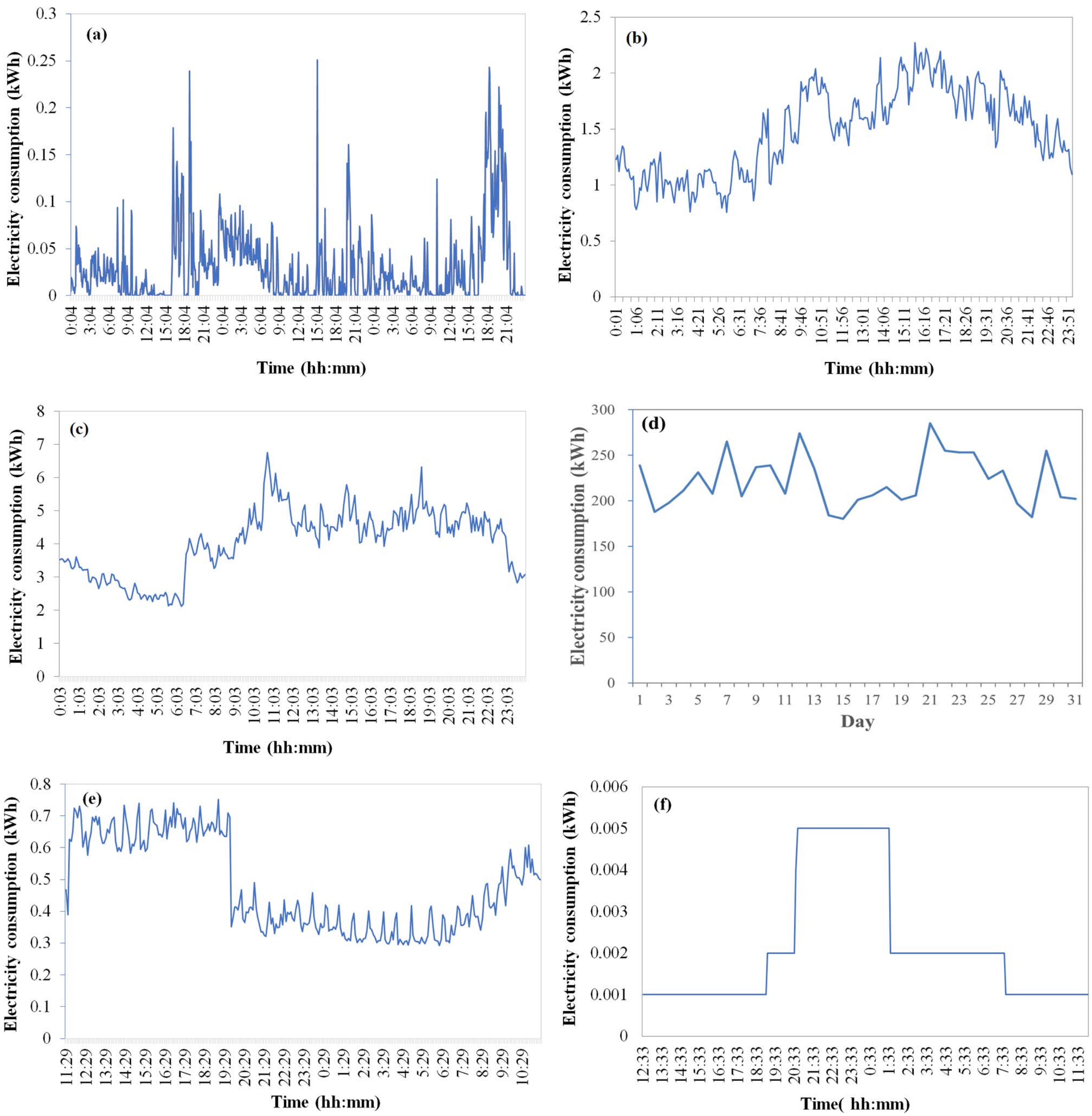

Figure 5. *Real-time electricity demand in the different areas of Hotel 1: (a) rooms, (b) poolbar, (c) kitchen, (d) spa, (e) common area lighting and (f) machinery.*

Machinery (Figure 5e) and lighting of common areas (except F&B areas) (Figure 5f) accounted for almost 5% (Figure 6) of the energy requirement. The lower consumption in machinery at night was due to an almost null use of water in these hours; in addition, the pool recirculation pumps were stopped for 2 hours each at night to prevent machinery wear. In the case of common area lighting, the consumption was almost null. It must be noted that all bulbs were LED and timers were installed in common areas.

For fuel consumption, propane was employed in the kitchen and gasoil in the boiler, as support for hot water production when the solar panels could not supply the total demand. The monthly consumption of propane was 8266 ± 1861 kWh and that of gasoil was 14988 ± 265.43 kWh. Thus, propane accounted for ∼35% of the energy from fuels and gasoil for 65%.

From the data shown in Figure 2, we determined that 27.36% of the total energy requirements in Hotel 1 were satisfied using fuel (propane and gasoil in this case). Thus, considering the above,

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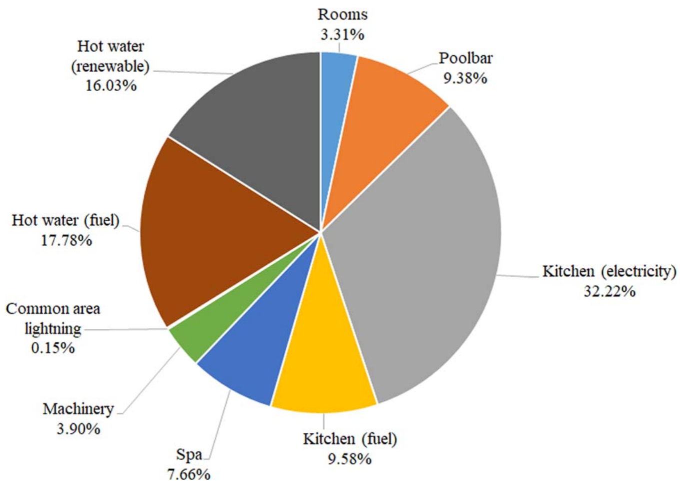

Figure 6. *Energy consumption by end-use.*

we can estimate that ∼9.58% of the total energy was provided with propane for cooking (kitchen) and ∼17.78% with gasoil for hot water (as support to the solar panels that account for 16.03% of the total energy). Therefore, considering both electricity and fuel consumptions, the distribution of energy requirements in the hotel per areas can be seen in Figure 6.

It has been reported (in 2013) that heating water with gasoil costs ∼0.2879 €/shower, while doing it with propane or biomass reduces this cost to 0.2408 or 0.1745 €/shower, respectively [37]. Considering that currently the price per kWh for gasoil is still higher than that of the other fuels mentioned, the susbtitution of the fuel for the auxiliary hot water system could reduce costs significantly. In addition, the CO_2 emissions per GJ are ∼15% lower for propane compared with gasoil [38].

Other authors have reported that ∼13% the total electricity is employed for hot water in hotels [39, 40]. The most consuming service has been reported to be HVAC, with 29–51% of the total electricity consumption [22, 39, 40]. Results differ from those found in this study, probably because the hotel studied here differs from those studied previously: no central air conditioning is included, it counts with a spa and most rooms have a shower plus a bathtub. In addition, it must be noted that the consumption of the cooling chambers is included in this study as part of the kitchen (electricity) section. This remarks the necessity to audit hotels independently or based on common characteristics.

3.5. Possibilities for renewable energy

According to the results from the previous sections, the F&B department accounts for most of the total energy and electricity consumption in the studied hotels. Electricity is the main energy source employed in all hotels. We attempt to determine, in general terms, the options for the installation of renewable solar energy in the six hotels of this study to calculate the possibilities of each building to reduce energy dependence on fossil fuels or external electricity sources.

Table 4. *Detail of the available surface for photovoltaic solar energy in each hotel.*

Hotel no.	Total active available surface (m^2)	Number of panels (n)	PV peak power (kW)
1	236.95	119	47
2	241.33	122	47
3	856.50	432	168
4	3260.40	1644	641
5	1125.40	568	221
6	146.18	103	40

A recent study reported that, for same collector surfaces, the combination of photovoltaic generation and heat pumps was the most profitability and less contaminant energy generation for hot water when compared with solar thermal systems [41].

Based on the above, in this study, we chose solar photovoltaic energy for calculations. First, we calculated the available surface area in each building for the installation of solar panels. Next, the distance between modules was calculated according to Equation (2) [42] and, finally, the total active available surface was then calculated from the total available surface area minus the area due to the distance between modules. These data are shown in Table 4.

$$d = \frac{l \cdot sen\beta}{\tan\left(61^\circ - latitude\right)}, \tag{2}$$

where d is the distance between the rows of panels or walls and panels, l is the length of the solar collector and β is the declination of the collector.

The photovoltaic module chosen for calculations was monocrystalline silicon Atersa A390M GS, with a peak photovoltaic power of 390 W (STC) and dimensions of 1979 × 1002 mm (1.98 m^2). The number of panels (n) to install was then calculated from the total active available surface divided by the surface of one panel (A_p), and the total photovoltaic peak power (P_{pp}) to install was calculated as follows:

$$P_{pp}(kW) = n \text{ x } P_p, \tag{3}$$

where Pp is the peak power of one panel.

The energy produced in the installations (E) was calculated following Equation (4):

$$E = G(\beta, \mu) \cdot PR \cdot P_{pp}, \tag{4}$$

where $G(\beta,\mu)$ is the mean irradiance according to a given declination and azimuth, *PR* comprises all losses of the system and P_{pp} is the peak power of the photovoltaic installation.

PR includes losses due to temperature (∼6%), wiring (∼3%), dispersion (∼2%), angular scattering (∼3%), the presence of dust on the panels (∼3%) and the efficiency of the inverter (∼5%).

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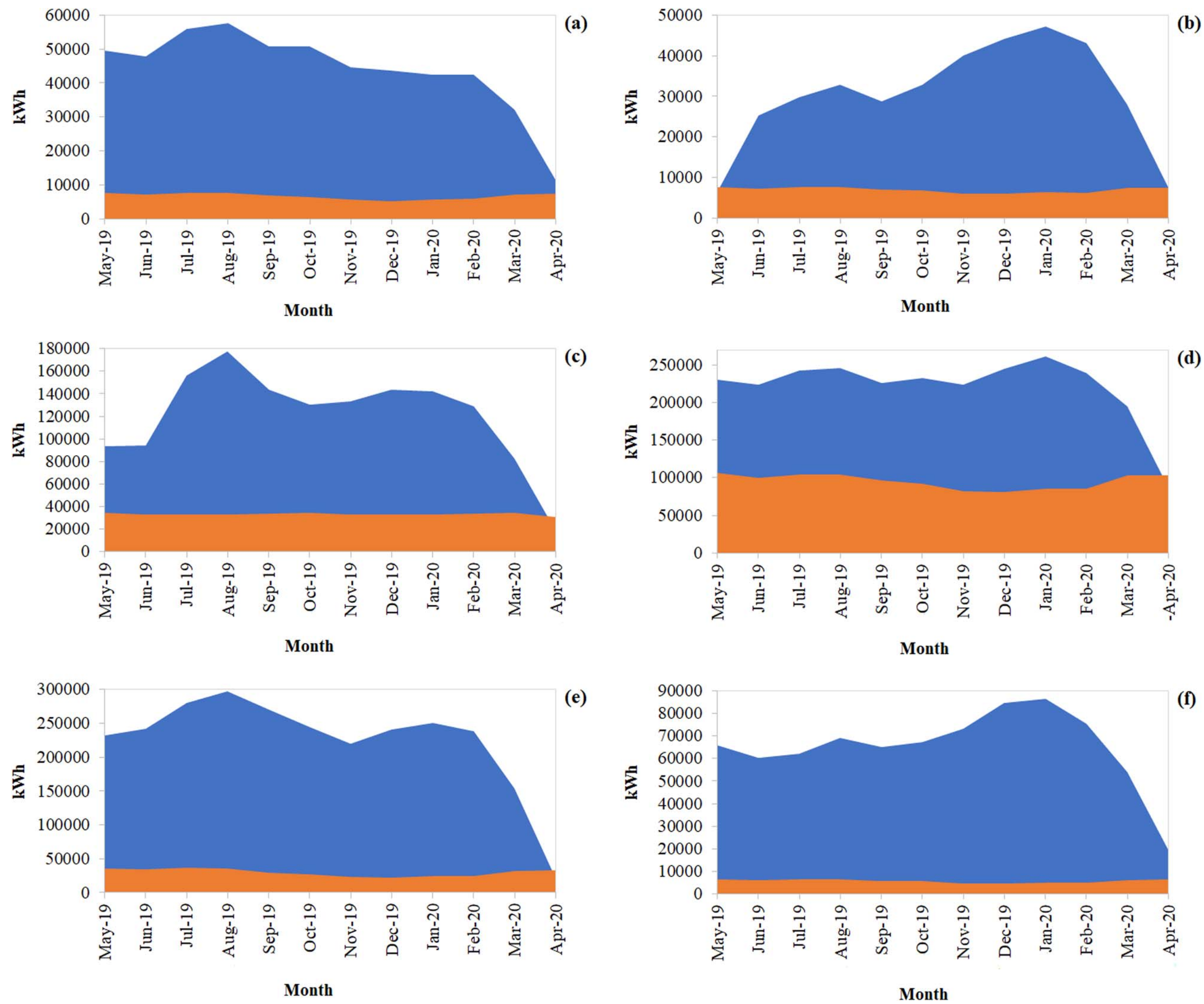

Figure 7. *Total electricity consumption (blue areas) in Hotels (a) 1, (b) 2, (c) 3, (d) 4, (e) 5 and (f) 6; solar photovoltaic possible contribution (orange areas).*

Losses due to temperature were calculated according to that specified in the technical sheet of the chosen panel: the temperature coefficient was −0.37%/°C and NOCT was 45 ± 2°C. The mean temperature of the solar cell (T_c) was calculated using Equation (5):

$$T_c = T_{amb} + (NOCT - 20) \cdot E/800, \quad (5)$$

where T_{amb} is the mean ambient temperature (∼18°C), *NOCT* is the nominal operating cell temperature and *E* is the mean solar irradiance at the location (∼799 W/m^2). It must be noted that all hotels are situated in the south of Gran Canaria: five hotels are in the municipality of Mogán and one (Hotel 5) in Playa del Inglés (San Bartolomé de Tirajana). The weather conditions are similar in these locations.

The Photovoltaic Geographical Information Systems [43] was used to determine the annual photovoltaic production in kilowatt-hour, given the exact location of the installations and keeping the slope of the panels equal to the latitude of the place (28°) and the azimuth equal to 0° for all hotels except for hotel 5. The roofs in Hotel 5 were tiled and the installation was calculated with the slope of the roof (30°) and azimuth equal to 0° (48% of the installation), 90° (26%) and −90° (26%), according to the direction of the different roof areas.

Figure 7 shows the resulting fraction of renewable solar photovoltaic energy over the total electricity consumption for each hotel. Here, we assumed that the daily generated energy is consumed with no surplus.

The mean contribution to the total energy demand of the new proposed photovoltaic installations is 8.03%, 29.13%, 26.48%, 30.01%, 9.21% and 5.93% for Hotels 1–6, respectively. The resulting energy mix is shown in Figure 8. It can be concluded that the possibility for solar photovoltaic energy clearly depends on the available area for the installation. This technology alone is not sufficient to self-supply any of the studied hotels, and further

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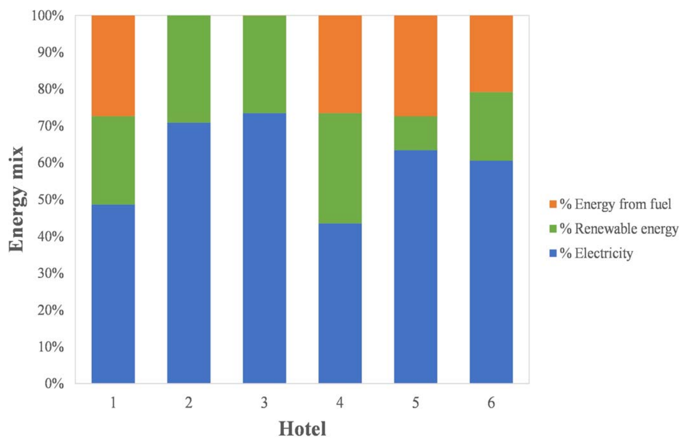

Figure 8. *Energy mix including the proposed solar photovoltaic contribution.*

studies are needed to optimize energy consumption, both considering operational and technical aspects such as the renovation of machinery, the insulation of walls and windows, etc.

4. CONCLUSIONS

The energy models of six different hotels were compared. From a regression analysis, we concluded that the energy demand depended on the RevPar, pool volume, number of diners and mean number of guests per occupied room. That is, the energy demand depended on the services offered. Hotels with no air conditioning or F&B service were those with lower energy consumption per pax. Those with all-inclusive F&B reported higher energy demands. The hotel with a spa and F&B service (although not all-inclusive) was the second hotel with mean annual highest energy demand per pax. This was Hotel 1.

Real-time monitoring of electricity consumption in Hotel 1 revealed that the F&B department is responsible for over 50% of the total energy demand. Although thermal solar panels were installed for heating water, an auxiliary boiler was needed for hot water production. This represented 65% of the energy consumed from fuels and accounted for almost 18% of the total energy demand in the hotel. Next, the spa had an energy demand of almost 8%. Machinery (pumps), rooms and lighting were the installations with lower energy demand.

The availability for solar photovoltaic energy was calculated for each hotel and we found that, according to the available space, between 8% and 30% of the total energy demand could be covered with this option. Thus, to achieve nearly zero energy buildings more actions would be needed.

Results suggest that a deeper analysis should be carried out to optimize the operational proceedings in the F&B department, as the energy demand in F&B areas seemed to be constant (for Hotel 1) at all opening hours and were not depending on the hours with more influx of clients (that is, in the morning for breakfast). In addition, the substitution of gasoil boilers is proposed to reduce the environmental impact and a deeper study on the insulation of the building should be carried out. These studies are out of the scope of this paper and are proposed for a future work.

It must be noted that the refurbishment of a building implies a legal requirement to move to more efficient energy systems. Although the use of renewable energy sources is scarce currently, this will surely change in the next years due to the need to update the hotels in the Canary Islands, most of which date from the 1980s.

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