Consumption and Emissions Analysis in Domestic Hot Water Hotels. Case Study: Canary Islands

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Abstract: We analyze the energy consumption of domestic hot water (DHW) in the hotels of the archipelago of the Canary Islands (Spain). Currently, systems use fossil fuels of propane and gas oil. However, this paper analyzes several alternative systems which focus on renewable and mixed energies, such as biomass, solar thermal and heat pumps systems associated with an electric generation with photovoltaic solar panels for self-consumption. The carbon footprint generated is calculated for each method of generation of DHW. In our analysis, we demonstrate that by using a high-temperature heat pump with an average coefficient of performance (COP) equal to or greater than 4.4 associated with photovoltaic solar panels, a zero-emission domestic hot water system can be achieved, when the installation area of the photovoltaic solar panels is equal to that of the solar thermal system. The importance of DHW's carbon footprint is proven, as is the efficiency of using high-temperature heat pumps associated with photovoltaic solar panels. As such, such mixed system suggests that the generation of DHW would have zero emissions with maximum annual savings according to hotel occupancy, between 112,417 and 137,644 tons of carbon dioxide (CO_2), compared to current boilers based on fossil fuels.

Keywords: Carbon Footprint; DHW; biomass; photovoltaic; solar thermal; heat pump

1. Introduction

One of the major factors of climate change is the emissions of CO_2, which mainly originate in natural organic and inorganic processes and by human energy generation [1]. As a result, many countries have introduced measures for energy production and consumption in economic activities. In addition to these energy efficiency measures, of the use of renewable energy systems (EERR) has emerged to achieve zero energy buildings (ZEB) [2] or near zero buildings (nZEB) [3]. It has been demonstrated in several successful projects in buildings around the world, such as the Zero Carbon Building in Hong Kong [4], the Hotel Mongkok Hong Kong [5], the Stadthalle of Vienna [6], or in the hotels of the European Union (EU) Nearly Zero-Energy Hotels (neZEH) project [7], which has achieved an average decrease of 63% in energy consumption and an increase in the use of EERRs up to 46% [8].

The 40% of total energy consumed and 36% of greenhouse gas emissions in EU correspond to buildings [9], estimating that 79% of energy is used for heating of water and air conditioning.

To alleviate this adverse effect, the EU has established short and medium-term objectives [10] for reducing greenhouse gas (GHG) emissions at 20% for the year 2020, use 20% of total energy consumption with EERR, for the year 2030 are a reduction of 40% of emissions in GHG, 27% of EERR, and an increase in energy efficiency by 27–30%, and as such, it is expected that the EU determines an 80–95% reduction in GHG emissions for the year 2050, as compared to values in the year 1990. Several directives on the reduction of consumption have been published to achieve these objectives, such as Directive 2010/31/EU [9] on energy efficiency in buildings [11]. Also, Directive 2012/27/EU [12] highlights the importance of promoting the energy efficiency of current and future buildings, with several studies on its application in the EU [13,14].

One of the critical fields of application of these regulations is tourist hotel buildings, because of the significant impact of tourism in society [15]. Tourism worldwide already represents 9% of the world's GDP, with an income of more than 1400 billion dollars [16], and a continuous increase in income in the last 20 years by 195%, generating 17.6% of global jobs. In the case of the study area of the archipelago of the Canary Islands (Spain), tourism represents 34.3% of GDP and generates 39% of employment [17]. It is worth mentioning that, in the projections of the world tourism organization (UNWTO), the tourist estimates up to the year 2030 include predicted values of 1800 million tourists [18], which doubles the values of 2010 and its associated emissions.

The energy consumptions and emission of a particular hotel can vary according to its geographical area, facilities, and categories of the establishments. For instance, the total energy consumption is divided into 22% for DHW, 14% for air conditioning (AC) and 21% for heating in hotels in Balearic Islands [19]; 31% for heating, 15% for AC and 17% for DHW hotels in the United States [20]; 47% for heating and 20% for DHW for hotels in Great Britain [21]; 35% for heating, 15% for AC and 22% for DHW in hotels in Greece [22]. Emissions also vary in establishments worldwide [23]. There is an average emission of 14.6 $kgCO_2$/overnight (CO_2/o) in several hotels in the island of Menorca [24], average values of 29 CO_2/o in 58 luxury hotels in Taiwan [25], values between 11.65 CO_2/o to 8.25 CO_2/o in hotels in Great Britain [26], and average values of 15.6 CO_2/o in hotels in the Canary Islands [27]. In total, the estimated average for global hotel stays [28] is 20.6 CO_2/o.

These values have motivated research on the emissions and consumption associated with the heating of DHW through different heating systems. Some examples are the heat pumps in hotels in the Canary Islands, which reduced energy consumption by 72% compared to LPG propane boilers [29]. Also, solar thermal systems in hotels in Greece, checking how their energy certification improves and obtaining a reduction of 67% in its emissions from the DHW [30]. Additionally, a hotel in California (USA) has shown a 33% energy saving and a return on investment in 4 years [31]. However, other centralized distribution systems using geothermal systems and absorption pumps achieved 100% utilization of EERR in Germany [32]. Satisfactory results have also been obtained using mixed systems of solar thermal equipment, connected in series with current systems [33]. In this context, we can find mixed systems of electric and solar boilers [34], mixed systems of AC and DHW [35], photovoltaic and thermal solar panels [36], and heat pump systems supplied by photovoltaic solar panels [37].

All of these studies have compared multiple heating systems, both in traditional systems of boilers with fossil fuels or biomass, systems based on solar thermal and mixed systems of heat pumps with power by photovoltaic solar panels. It has allowed for obtaining reference values on the efficiency and emissions of the different systems.

Considering the hotel buildings in Spain, one must take into account their 25% variation due to seasonal closures, with maximum values of 16,836 hotels for the summer months [38]. Because of these variations, we have focused on a more stable destination, such as the Canary Islands, with 628 hotels offering more than 247,000 hotel beds [39] during the whole year. In this article, we carry out the comparison of these models in current hotel facilities, and in a destination of high ecological value, the sustainability of which is essential and complicated, and with a stable annual hotel occupancy throughout the year. To this end, the case studied is the Canary Islands (Spain), where the 63% [40] of

the archipelago's surface is declared a Biosphere Reserve. Thus, results obtained can be applied to other zones of similar geographic and environmental characteristics.

This paper is organized as follows. Section 2 describes the methodology followed in our study. In Section 3 we calculate the required DHW, and its effect on the carbon footprint and the discussion of the results is provided in Section 4. Conclusions are given in Section 5.

2. Methodology

As a research area, we have chosen the archipelago of the Canary Islands. It is located in the Mid Atlantic Ocean near the coast of southern Morocco and the Sahara, northern Africa. It has an arid climate, where certain areas have a desert climate or belong to a dry subtropical environment [41], according to the collected data of the open establishments during the year 2017 [20]. Table 1 summarizes the types of existing hotels by category and the current establishment of each class. These average conventional establishments are based on the calculations of energy and water needs; the different fuels and models were converted to the same unit of measurement. It allows for comparison between the generating models, the water in cubic meters (m^3) and the energy at kWh, transforming the values of the different fuels, according to the primary energy conversion factors for each of them [42,43].

Table 1. Hotels in the Canary Islands and hotel standards by category.

	Type	1 Star	2 Stars	3 Stars	4 Stars	5 Stars	Total
Hotels	Total	110	76	149	246	47	628
Beds	Total	1668	3998	25,212	67,399	13,028	111,305
	Standard hotel	15	53	169	274	277	177
Rooms	Total	3548	11,135	60,879	143,172	28,332	247,066
	Standard hotel	32	147	409	582	603	393

We have studied the DHW needs of the hotel establishments and the CO_2 emissions associated with the production of the DHW. Specifically, we followed the workflow shown in Figure 1, which is summarized as follows:

1. Data collection of hotel establishments in the Canary Islands open during the year 2017.
2. Calculation of the standard hotel according to the category of the establishment: places and rooms by category.
3. For each standard hotel of each type, calculation of annual DHW needs per month and the total for all the hotels in the archipelago.
4. With the DHW needs data, the energy required for water heating by category of each standard hotel and the total number of hotels in the Canary Islands.
5. Calculation of the heating system regarding the thermal solar collectors by the F-Chart method [44,45] to cover a minimum of 70% of the annual thermal needs and the lack of support energy, from the current systems based in fossil energies.
6. The same surface of the solar thermal system is used to install photovoltaic solar panels and the equivalent electrical generation for self-consumption. This energy is used to feed heat pumps, calculating the energy needs for this system.
7. Having in mind the hypothesis that the current technologies are based on fossil fuels of LPG propane and diesel, we calculate the energy needs for this type of boiler and also for biomass boilers with pellet fuel.
8. Carbon footprint comparison in different technologies by category, for all the hotels in the Canary Islands.
9. Conclusions and future needs to achieve sustainable and efficient buildings in terms of the DHW systems in the Canary Islands.
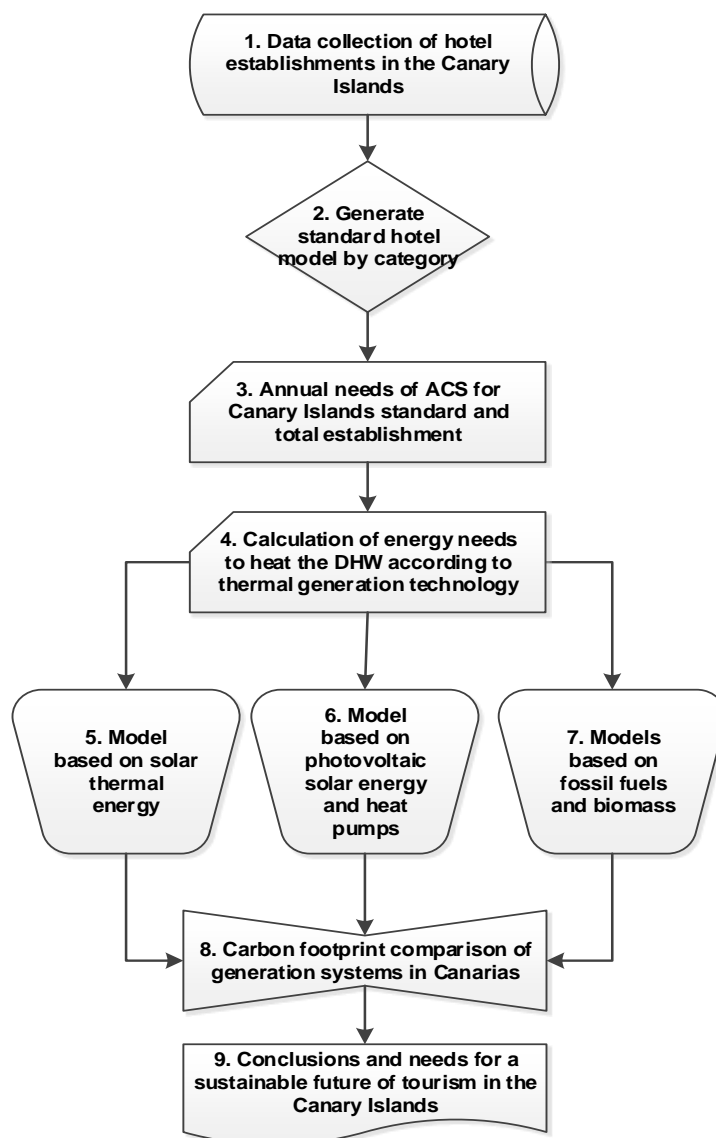
Figure 1. Overview of the research flowchart.

3. Results: Calculations of DHW's Needs

The DHW needs calculations is estimated for DHW consumption in the establishment. The tabulated data are used according to the type, category and occupation of establishment [46], which appear in the different regulations and technical guides. We use the standard values of the Spanish Association for Standardization (UNE) 94002:2005 [47] standard, which are closer to the reality of the current buildings that are marked by the latest standards of the technical building code (CTE) in force in Spain [48,49] for new buildings. In Table 2 we compare the consumption data for the calculation. It is observed a gradual decrease, with significant differences of more than 30% in some cases for new buildings. However, the current ones are calculated with the values of the previous regulations, which have higher consumption values.

The accumulation temperature must be at least 60 °C, due to Legionella regulations [50]. Moreover, we use the Canarias network temperature data from the UNE 94003:2007 standard for Las Palmas de Gran Canaria, the calculations consider the energy losses in the DHW recirculation and return systems, which have been estimated at 10%. Also, other losses of 5% have been taken into account. In this way, we obtain the needs for DHW by month and category, for the group of hotels on the islands. According to the UNE 94002:2005 standard, the following Equation (1) is used to calculate the needs for DHW:

$$E_{DHW} = (Q_{ref} \cdot \rho \cdot Cp \cdot (T_{ref} - T_W)) / (1 - L_R - L_O) \tag{1}$$

where "Q_{ref}" refers to the DHW consumption of the hotel type at the reference temperature, "ρ" the water density, "Cp" the specific heat at constant water pressure, "T_{ref}" temperature of the DHW for use, "T_W" water temperature of the network, "L_R" lost in the hotel network and "L_O" other losses. The calculus of E_{DHW} provides the necessary energy per hotel category and for all of the hotels. Figure 2 shows the increase in energy needs with the increase in the category of hotels and the sum of the energy needs of all hotels in Canary Islands by category, verifying the importance of the consumption of four-star hotels, which represent 61% of the total the energy needs. The sum of the three main categories of hotels is also made, which represents 96% of the total energy consumed. Regarding the obtained results, we can conclude that these three top categories require more effort to reduce the energy consumption of the DHW in the Canarias hotel sector.

Table 2. Average unit consumption per room according to different standards by category.

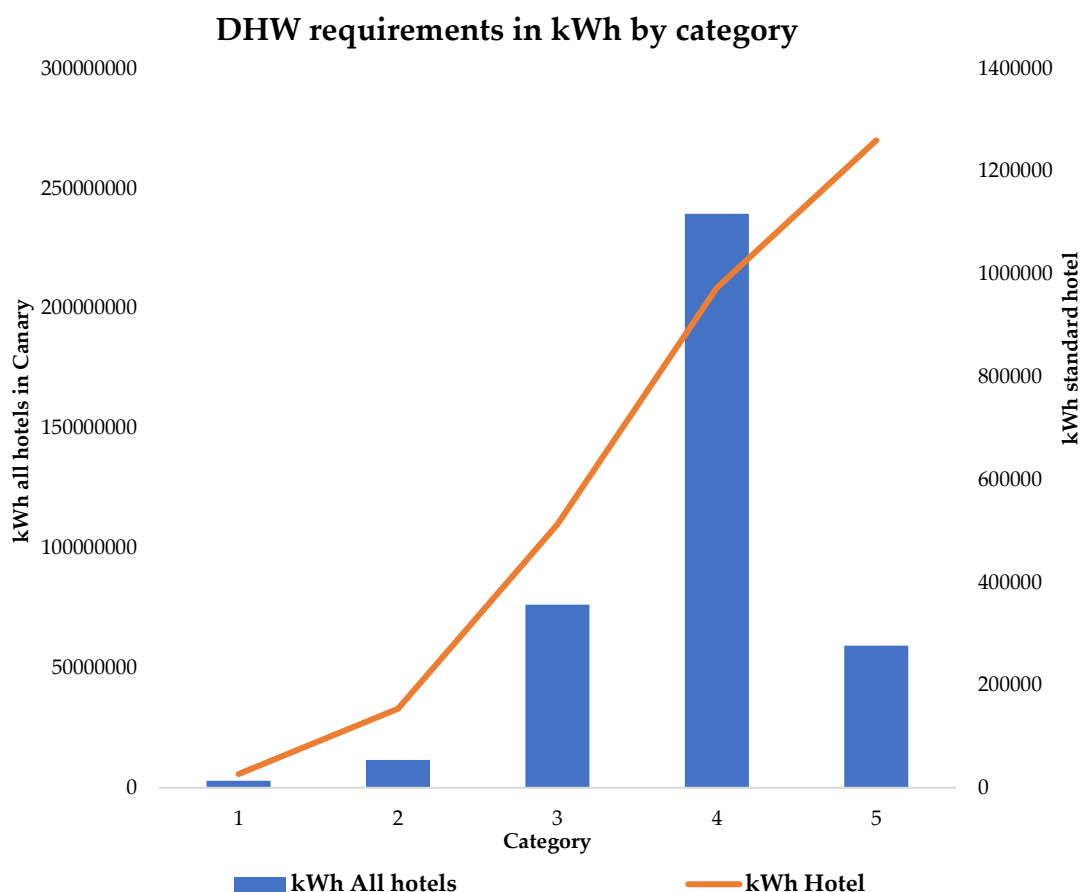| **Normative**		**1 Star**	**2 Stars**	**3 Stars**	**4 Stars**	**5 Stars**
	UNE94002 [46]	40	50	60	80	100
DHW Litters to 60 °C for bed	CTE 2006 [47]	35	40	55	70	70
	CTE 2017 [48]	28	34	41	55	69

Figure 2. Energy requirements for the domestic hot water (DHW) for each standard hotel and for the entire group of hotels in the Canary Islands by category.

Assuming the calculated data of total energy needs and for each category of hotel, we examine the following heating systems: LPG propane boilers, diesel boilers, biomass boilers with pellets, solar thermal boilers with a support system for boilers LPG propane or diesel current and mixed

systems of photovoltaic solar generation and heat pumps. Table 3 shows the main characteristics of the photovoltaic and thermal solar panels chosen for the study.

Table 3. Features selected thermal and photovoltaic solar panels.

	Photovoltaic	Solar Thermal
Model	Atersa A330PGSE	Kairos XPS2.1-1H
Surface total m^2	1.94	2.52
Surface solar collector m^2		2.241
Coefficient linear losses Wm^2/°K		3.015
Coefficient secondary losses W^{2}m^2/°K		0.017
Optical performance		0.812
Maximum power W	330	
Operating temperature	45	
Coefficient variation T°	−0.43%	

3.1. Thermal Panels Calculations

The CTE [48] and the Regulation of thermal installations in buildings (RITE) [51] establish that the minimum coverage by EERR for the DHW in the Canary Islands must be 70%. Therefore, we use it as the minimum value for calculating the thermal solar panels to be installed in the different hotels. The irradiation data that we will use for the calculations are provided by the UNE 94003:2007 standard. The angle of inclination of the panels is a crucial factor. It has significant repercussions for useful radiation, mainly on the surface occupied by the modules. The reason is the minimum separation between rows or obstacles, the value of which is given by the following Equation (2):

$$D = L \cdot sen\alpha / tg(61 - Lat) \tag{2}$$

where, "D" denotes the distance between panels or obstacle, "L" the height of the obstacle or panel, "α" the inclination of the solar panel and "Lat" the latitude of the installation.

We use the F-Chart method [44,45] to estimate the solar coverage. This method is typically used for the annual thermal performance of heating systems for DHW, in many installations with acceptable forecast results [52]. This method estimates the fraction of thermal energy that will be supplied by solar energy. The primary design variable is the collector area, whereas the secondary variables are: the collector type, the amount of DHW storage and the size of the collector heat exchanger. This method is based on a correlation of the results of many hundreds of thermal performance simulations of solar heating systems. The following Equations (3)–(5) are obtained by using the F-Chart method:

$$F = 1.029D_1 - 0.065D_2 - 0.245D_1{}^2 + 0.0018D_2{}^2 + 0.0215D_1{}^3 \tag{3}$$

$$D1 = Fr(\tau\alpha)_N \frac{F\prime r}{Fr} \left[\frac{\overline{\tau\alpha}}{(\tau\alpha)_N} \right] \overline{Ht} N \frac{Ac}{L} \tag{4}$$

$$D2 = FrUl \frac{F\prime r}{Fr} (Tref - Ta) \Delta t \frac{Ac}{L} \tag{5}$$

where, "Ac" is the area of solar collector, "F′r" the collector-heat exchanger efficiency factor, "Fr" the collector heat removal factor, "UL" the collector overall energy loss coefficient, "Δt" the total number of seconds or hours in the month, "Ta" the monthly average ambient temperature, "L" the monthly total heating load, "HT" the monthly averaged daily radiation incident on collector surface per unit area, "N" the number of days in the month, "τα" the monthly average transmittance-absorptance product, "(τα)" the normal transmittance-absorptance product and "Tref" the reference temperature.

In order to optimize the space and maximize the irradiation with the minimum collector surface, the angle of inclination of the panels is set at 15°. Experimental results for the different inclination values, necessary installation surface and irradiation difference are given in Figure 3 obtained for

the sum of all hotels the Canary Islands. The chosen angle of inclination of 15° provides a moderate use surface, since the highest values close to the ideal of 25° imply that the main surface increases by 15% and the annual useful irradiation only increases by 0.8%. In addition, this chosen angle helps the evacuation of water and dust, mainly due to the dust of the Sahara or Calima [53,54], which reaches the Canary Islands.
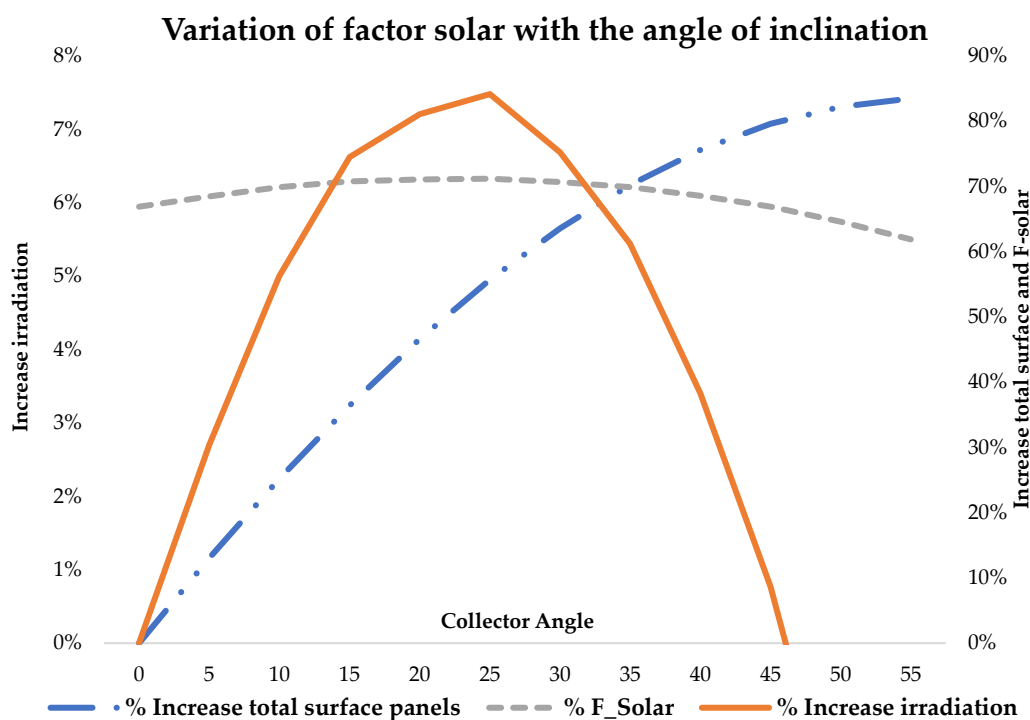

Figure 3. Radiation distance between collectors and solar factor according to the slope of the collectors.

Next, we work out the average values for thermal solar installations. Mainly, we calculate the number of collectors, the surface of the floor used, DHW accumulation needs, the annual solar factor, the thermal energy generated and the missing energy, as it is shown in Table 4. These values are supposed to be covered by another auxiliary heating system, which in this study will be covered by the existing LPG propane or diesel boilers.

Table 4. Values obtained for thermal solar installations for the standard hotel by category.

Category	N° Collectors	Total Surface Collectors m²	Accumulation L	F-Solar %	Thermal Energy Generated kWh	Thermal Energy Missing kWh
5 Stars	430	1479	50,000	70.4%	886,335	373,359
4 Stars	330	1135	40,000	70.2%	682,876	289,783
3 Stars	170	585	30,000	70.3%	360,280	152,371
2 Stars	50	172	15,000	70.9%	108,799	44,746
1 Star	9	31	2000	71.7%	19,166	7574

Then, we can obtain the needs for all hotels in the Canary Islands. The annual average values of coverage of 70.3% of annual thermal needs are obtained through thermal solar panels. Figure 4 shows the energy values generated by the thermal solar panels, missing energy that must be covered by the current boilers and the solar fraction obtained monthly, for all the hotels in the Canary Islands. As previously mentioned, the missing energy is supplied by the current LPG propane or diesel boilers.
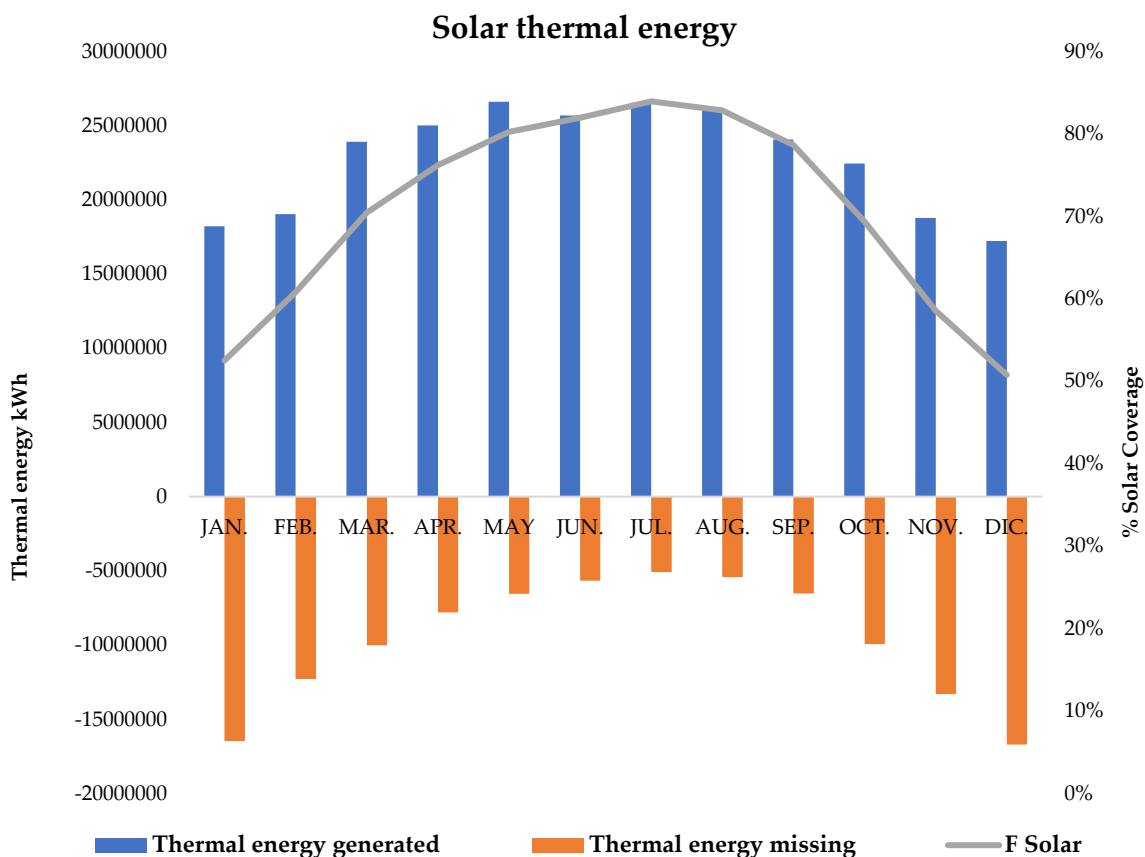
Figure 4. Generation of thermal energy obtained by solar collectors, monthly needs and solar coverage factor for all Canary hotels.

3.2. Calculations Photovoltaic Panels + Heat Pumps

Once the available area for solar thermal panes is known, we calculate the photovoltaic solar panels to match the installation surface of solar thermal systems. We aim to occupy the same space in hotel buildings.

On the one hand, the UNE 94003:2007 standard provides the irradiation values of the available area. As such, we deduce the monthly electricity generation of the facilities. Prior studies have used such standards to adjust forecasts to the real generation values [55]. Also, the maximum power of the generator and the total losses must be calculated, which are included in a total efficiency index known as "Performance Ratio" (PR). The following Equation (6) is used to calculate the generation of each installation per month:

$$E_{red} = G(\beta, \mu) \cdot PR \cdot P_{PP} \tag{6}$$

where "$G(\beta,\mu)$" denotes the mean irradiance according to declination and a given azimuth, "PR" the global loss index that encompasses all losses of the system, and "P_{PP}" the maximum power of photovoltaic generators. PR is obtained by considering all the losses of the generating system, which is given by the Equation (7):

$$PR = \left(1 - (L_T + L_D + L_R + L_P)\right) \cdot L_E \cdot L_{In} \cdot L_V \tag{7}$$

where, "L_T" denotes the losses by temperature, calculated by the method of Osterwald [56]. "L_D" refers to the losses by dispersion of parameters (2%), "L_R" the losses by angular and spectral reflectance (3%), "L_P" the losses due to dust on the modules (3%) and in the Canary Islands due to the episodes of Calima. The latter parameter is essential since it may arise higher values whether the modules are not cleaned regularly, Also, "L_E" denotes the efficiency in electrical wiring (97%), "L_{IN}" the efficiency

due to the efficiency of the inverter (94%). In our case, we use the European efficiency value [57] of the inverter given by the manufacturer. Finally, "L_V" is another efficiency parameter, that was not previously considered (97%).

The same angle of inclination (15°) previously set in the thermal solar panels as the occupied surface by category, is used in photovoltaic modules. This is so that the number of photovoltaic solar panels and the maximum installed power are calculated. Table 5 shows the values obtained for electricity generation for standard hotels by category, monthly and annual total.

Table 5. Monthly and annual electricity generation in kWh by hotel according to the category.

	CATEGORY	1 Star	2 Stars	3 Stars	4 Stars	5 Stars
	N° Collectors	12	65	220	430	560
	Used surface m^2	32	172	582	1138	1483
	Installed power kW	3.96	21.45	72.6	141.9	184.8
	JAN.	404	2189	7410	14,484	18,863
	FEB.	422	2285	7734	15,116	19,686
	MAR.	538	2915	9,865	19,282	25,111
	APR.	568	3075	10,408	20,343	26,493
	MAY	615	3329	11,268	22,024	28,682
	JUN.	597	3236	10,954	21,410	27,883
Electricity generation in kWh	JUL.	618	3347	11,328	22,141	28,835
	AUG.	603	3267	11,057	21,612	28,146
	SEP.	544	2948	9978	19,502	25,398
	OCT.	498	2698	9131	17,846	23,242
	NOV.	417	2259	7647	14,947	19,465
	DIC.	385	2087	7065	13,808	17,983
	TT	6210	33,636	113,845	222,515	289,787

Then, we calculate the water heating system for DHW based on heat pump by using monthly and annual generation data. For this purpose, different heat pump efficiencies with COP values are used. We start with a minimum value of 2 for older equipment up to a maximum of 8 for more modern equipment. Modern equipment has optimum operating conditions and high-efficiency dissipation systems by aerothermal, geothermal or hydrothermal. Figure 5 shows the results for the total energy requirements for hotels in the Canary Islands. It is observed that systems with a COP equal to 4.4 produce zero emissions and equipment with a higher COP consume less energy than that generated by photovoltaic systems. The energy left over could be used for self-consumption producing a general decrease in emissions from hotel establishments. It is also verified that the characteristic function that describes the curve of necessary or excess energy of the heat pumps concerning the efficiency of the machines corresponds to a logarithmic function, which has a very high correlation index for all its values.

$$E = -46771 \cdot \ln(COP) + 120321 \tag{8}$$

We calculate the consumption of heat pumps for all hotels in the Canary Islands. To this end, we check whether the photovoltaic solar panels help to supply the energy necessary to cover the needs of the DHW, except from October to February, which require an external supply. However, the annual demand for electricity is covered by the total amount of energy generated in the remaining months from March to September. Figure 6 shows the photovoltaic generation obtained and the surplus or lack of electrical energy to cover the needs of heat pumps with an average COP of 4.4, monthly.
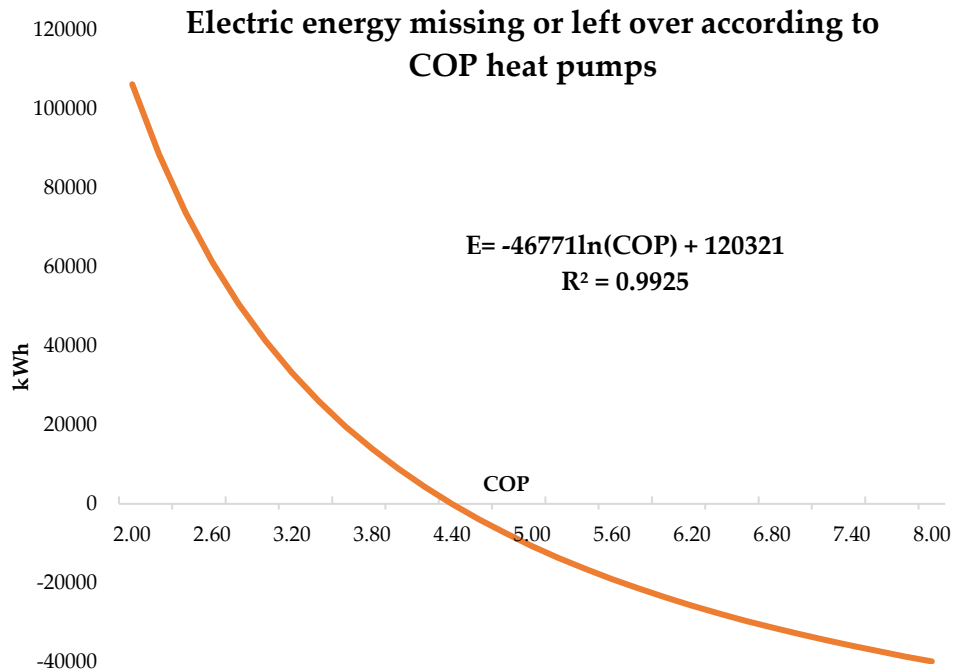
Electric energy missing or left over according to COP heat pumps

$$E = -46771\ln(COP) + 120321$$
$$R^2 = 0.9925$$

Figure 5. Values of energy generated by the solar panels for DHW heating using heat pumps according to the coefficient of performance (COP) efficiency of the equipment used.
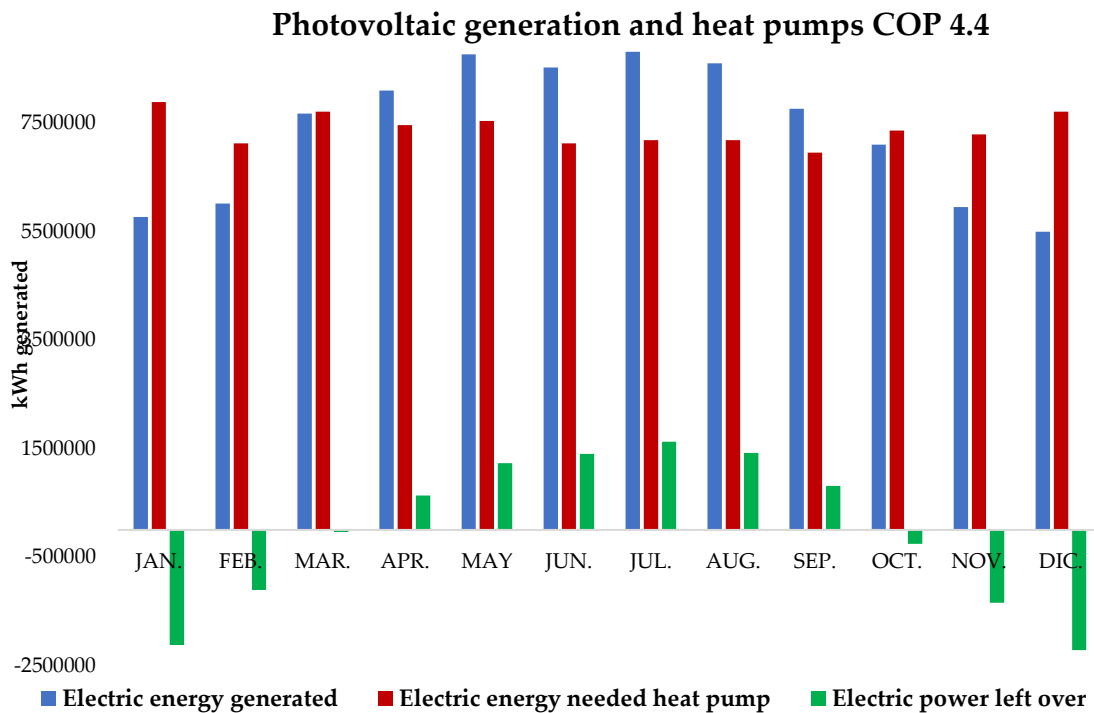
Photovoltaic generation and heat pumps COP 4.4

■ Electric energy generated   ■ Electric energy needed heat pump   ■ Electric power left over

Figure 6. Photovoltaic generation and energy need of heat pumps, as well as the surplus or lack of monthly energy for all hotels in the Canary Islands.

3.3. Fossil Combustible Calculations and Biomass

Systems based on fossil fuels such as LPG, propane or diesel and biomass are used to calculate energy needs. Correctly, we use the average efficiency for all boiler operating regimes, with an estimated value of 88%. To quantify fuel requirements, the conversion coefficients of the different fuels converted

to kWh are used. We show these values in Table 6, according to the Institute for Energy Diversification and Saving (IDAE) [42].

Table 6. Conversion factors of different fuels.

Fuels	Conversion Factors
Diesel	10.28 kWh/L
LPG Propane	12.75 kWh/kg
Pellet in general	4.57 kWh/kg

In Table 7 we show the number of necessary fuels per month as well as the total year values to heat the DHW for all hotels in the Canary Islands. They are obtained once the energy needs, the efficiency of the boilers and calorific value of the fuels, are obtained.

Table 7. Needs of fossil fuels and pellets for all hotels in the Canary Islands.

	Pellet kg	LPG Propane kg	Diesel L
JAN.	8,627,078	3,092,215	3,835,189
FEB.	7,792,200	2,792,969	3,464,042
MAR.	8,435,365	3,023,500	3,749,963
APR.	8,163,257	2,925,967	3,628,996
MAY	8,243,653	2,954,784	3,664,737
JUN.	7,792,200	2,792,969	3,464,042
JUL.	7,860,227	2,817,352	3,494,284
AUG.	7,860,227	2,817,352	3,494,284
SEP.	7,606,671	2,726,470	3,381,565
OCT.	8,051,940	2,886,068	3,579,510
NOV.	7,977,728	2,859,468	3,546,519
DIC.	8,435,365	3,023,500	3,749,963
Year	96,845,911	34,712,613	43,053,094

4. Discussion. The DHW Carbon Footprint

The energy needs of the different heating models and the previously calculated fuel needed are used to analyze the emissions associated with the different systems studied. We calculate the carbon footprint of the different heating systems, as the European Commission regulations suggest using multiple models and existing standards [58]. In our study, we have used the Greenhouse Gases Protocol (GHG) [59], widely used by organizations around the world. Scopes 1 and 2 of fuels and electricity were calculated for heating the DHW. We quantify the emission factors and the CO_2 emission values, which are approved and updated for Spain were used [42]. They are given in Table 8, the emission factors of electricity changes yearly or even monthly. In this way, we estimate emissions with the average emission data from the last year 2017 [60] and if all hotels have own transformer, with a medium voltage supply that generates losses of 6% in medium voltage lines.

Table 8. Emission factors of different fuels and electricity.

Fuel	CO_2 Emission Factors
Diesel	0.311 kg/kWh
LPG Propane	0.254 kg/kWh
Pellet in general	0.018 kg/kWh
Electricity in the Canary Islands	0.827 kg/kWh

Taking into account these emission factors, and the energy needs according to the fuels, the emissions of each of the water heating systems are calculated. The calculation is based on the category of hotel and

for all the hotels in the Canary Islands. Table 9 summarizes the energy needs by category, the associated emissions by hotel and for the total number of hotels, showing the total value of energy needs and emissions for all the hotels in the Canary Islands. It can be seen how the mixed system of heat pumps with a minimum COP of 4.4 and photovoltaic solar panels cover all the energy needs of the DHW system, suggesting a zero emissions system. In addition, the case study generates excess energy, which could be used in the self-consumption of hotel facilities. Category 2- and 3-star hotels are the only shortfalls in total annual energy, which is why it is necessary to carry out support with external energy supply. The proposed mixed system stops emissions, with maximum annual savings according to hotel occupancy, between 112,417 to 137,644 tons of CO_2, which are emitted by current heating systems based on fossil fuels.

Figure 7 compares the total emissions of all hotels in the Canary Islands. It can be seen that the system based on the mixed model of photovoltaic solar energy and heat pumps produces zero emissions with the same surface area of collectors as solar thermal systems. Systems based on biomass boilers are the following with the lowest emissions. However, one difficulty of the study area is the carbon footprint generated by the transport of pellets to the Canary Islands, which is very high because of transportation issues [61].
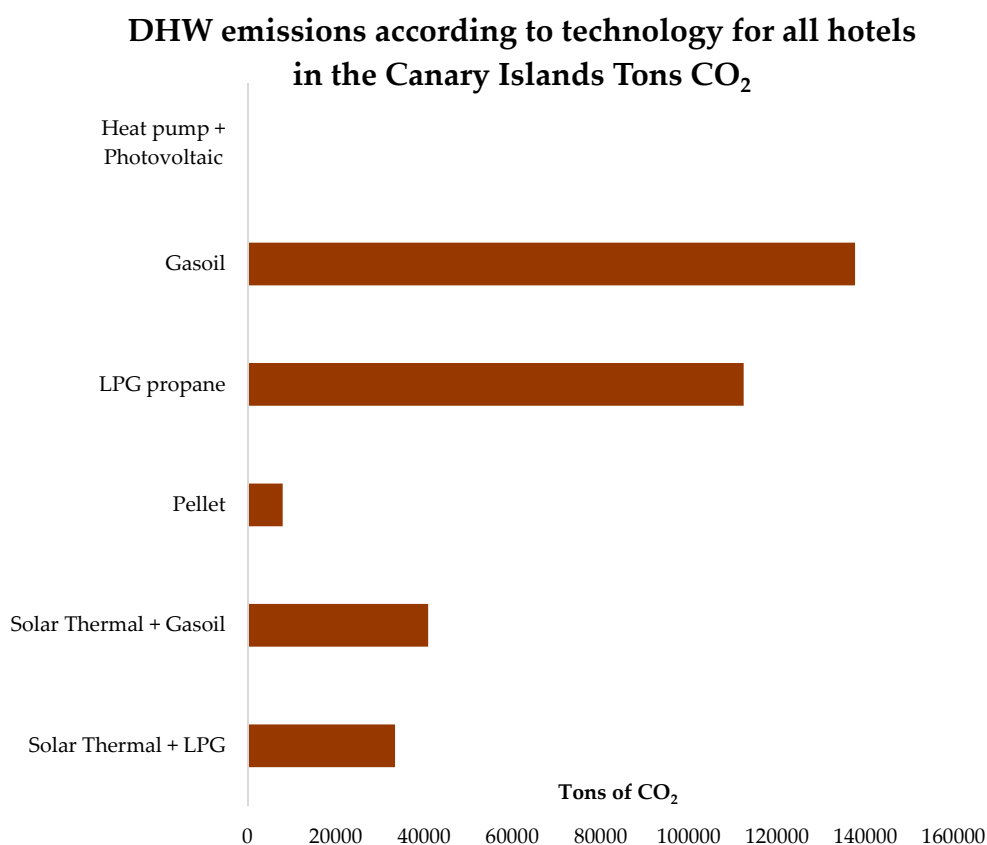

Figure 7. Summary of emissions due to DHW of the different technologies used for all the hotels of the Canary Islands.

Table 9. Summary of energy needs and emissions of the different heating models of DHW by hotel and for all the hotels of the Canary Islands.

Hotel Category, Type of Fuel and Emissions		Solar Thermal		Pellet	LPG Propane	Gasoil	Photovoltaic	Heat Pump COP 4.4	Heat Pump + Photovoltaic
		+LPG Propane Kg	+Gasoil L	kg	kg	L	kWh	kWh	kWh
1 Star	Hotel Fuel	675 kg	837 L	6649 kg	2383 kg	2956 L	6210 kWh	6077 kWh	−133 kWh
	Total fuel	74,255 kg	92,097 L	731,394 kg	262,155 kg	325,143 L	683,070 kWh	668,494 kWh	−14,576 kWh
	Hotel kg CO_2	2186	2677	547	7718	9450	−5134	5025	−110
	Total kg CO_2	240,476	294,441	60,164	848,987	1,039,508	−564,762	552,711	−12,052
2 Stars	Hotel Fuel	3988 kg	4946 L	38,180 kg	13,685 kg	16,973 L	33,636 kWh	34,897 kWh	1260 kWh
	Total fuel	303,090 kg	375,915 L	2,901,681 kg	1,040,053 kg	1,289,950 L	2,556,339 kWh	2,652,136 kWh	95,798 kWh
	Hotel kg CO_2	12,915	15,814	3141	44,319	54,264	−27,810	28,852	1042
	Total kg CO_2	981,558	1,201,829	238,692	3,368,213	4,124,072	−2,113,581	2,192,786	79,206
3 Stars	Hotel Fuel	13,580 kg	16,843 L	127,474 kg	45,691 kg	56,669 L	113,845 kWh	116,512 kWh	2667 kWh
	Total fuel	2,023,468 kg	2,509,651 L	18,993,699 kg	6,807,937 kg	8,443,697 L	16,962,910 kWh	17,360,241 kWh	397,330 kWh
	Hotel kg CO_2	43,980	53,849	10,486	147,970	181,176	−94,127	96,332	2205
	Total kg CO_2	6,553,000	8,023,555	1,562,422	22,047,505	26,995,174	−14,024,934	14,353,447	328,513
4 Stars	Hotel Fuel	25,827 kg	32,033 L	241,859 kg	86,690 kg	107,519 L	222,515 kWh	221,059 kWh	−1456 kWh
	Total fuel	6,353,521 kg	7,880,096 L	5,949,7236 kg	21,325,676 kg	26,449,647 L	54,738,762 kWh	54,380,474 kWh	−358,288 kWh
	Hotel kg CO_2	83,642	102,412	19,895	280,745	343,746	−183,976	182,771	−1204
	Total kg CO_2	20,575,877	25,193,298	4,894,243	69,063,202	84,561,637	−45,258,009	44,961,776	−296,233
5 Stars	Hotel Fuel	33,276 kg	41,272 L	313,232 kg	112,272 kg	139,248 L	289,787 kWh	286,294 kWh	−3493 kWh
	Total fuel	1,563,981 kg	1,939,762 L	14,721,901 kg	5,276,791 kg	6,544,658 L	13,620,006 kWh	13,455,817 kWh	−164,189 kWh
	Hotel kg CO_2	107,765	131,948	25,766	363,593	445,187	−239,596	236,708	−2888
	Total kg CO_2	5,064,952	6,201,575	1,211,024	17,088,888	20,923,796	−11,261,021	11,125,270	−135,751
TOTAL	Fuel	10,318,315 kg	12,797,521 L	96,845,911 kg	34,712,613 kg	43,053,094 L	88,561,087 kWh	88,517,162 kWh	43,925 kWh
	kg CO_2 TT	33,415,862	40,914,698	7,966,545	112,416,796	137,644,187	−73,222,307	73,185,990	−36,317

5. Conclusions

In this paper, we have assessed more efficient and less polluting systems in energy consumption in hotels. Specifically, we have focused on DHW, since it is one of the primary energy consumers. We have studied different possibilities of generation of DHW using systems based on renewable energy and compared them with current energy generation systems based on fossil fuels. Our analysis of solar thermal and photovoltaic systems, sharing the same collector surfaces, suggested that the most profitability energy generation is the combination of photovoltaic generation and heat pumps. Such a combination led to better results regarding efficient and harmful emissions. Also, improvements in the energy autonomy of the buildings for heating the DHW were observed, reducing its external energy dependence and the carbon footprint associated with tourism.

The models based on solar thermal energy have proven the problem associated with the need for a second source of energy to cover the total demand of the system, which increases the need for investment and external energy dependence.

As such, our study also suggests that benefits are obtained when self-generation through photovoltaic solar panels. Such solar panels are associated with heat pumps with higher COP efficiency values. As such, our study also suggests that benefits are obtained when self-generation through photovoltaic solar panels, and we demonstrate that using high-temperature heat pump with an average COP equal to or greater than 4.4 associated with photovoltaic solar panels, a zero-emission DHW can be achieved, when the installation area of the photovoltaic solar panels was equal to that for solar thermal system. When solar panels are associated with heat pumps with higher COP efficiency values, it entails higher savings and very fast amortizations of the systems, improving, therefore, the efficiency of equipment and the effectiveness of current photovoltaic solar panels, this being the main direction for achieving the energy independence of these buildings.

Finally, the Canary Islands is a sensitive and vulnerable tourist destination, with great external energy dependence and great ecological value. Toward a more efficient technological use of this technology and reduction in the pollution, we plan to develop the experimental improvements of this study in existing buildings in our future works. As has been demonstrated in the studied context, the use of EERR is an excellent way to achieve the goal of converting current buildings into ZEB or nZEB, based on improvements in current DHW heating systems.

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