Conference Proceedings

EuroSun 2014
Aix-les-Bains (France), 16 – 19 September 2014

Analysis of Demand and Energy Saving at Different Types of Hotels with Integration of Solar Systems and Geothermal Heat Pumps

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Summary

Performance analyses for integration of solar thermal, PV and geothermal heat pumps to different hotel typologies have been carried out in order to evaluate the potential of self-consumption promoted by European Directives. Hotels are located in different climatic zones of Spain and Italy. Using the software TRNBuild®, the buildings have been created and run under TRNSYS Simulation Studio. Four typologies of hotels (urban, rural, beach and mountain) and five categories of guests were created (family, couple, youth, organized travel group and business), reflecting existing different patterns of energy consumption. Three Spanish provinces and one mountain site in Italy with different weather conditions have been selected to calculate total thermal, electrical and domestic hot water (DHW) demand. Systems were sized to cover approximately 70% of DHW demand, according to Spanish Normative. In addition, by using the selected technologies it is possible to supply all the electricity demand according to different patterns. In particular, it will be shown that it is possible to supply 50% of total energy with PV panels - a value above the objectives of the European Union for 2020.

Keywords: Near Zero Energy Building; Smart Energy Building, TRNSYS; Self-consumption; Solar DHW, Photovoltaic, geothermal heat pumps

1. Introduction

Nowadays, concepts such as “near zero energy building” and “smart energy building” are very common. These concepts promote the reduction of energy consumptions and integration of renewable energy systems into buildings. After publication of the European directive for the energy performance of buildings (European Parliament and Council, 2010), several policies and specific projects have been promoted and financed to improve technologies and disseminate that concepts. The German institution ENOB (Research for Energy Optimized Buildings) highlights some of the smart buildings realized in Europe and in the rest of the world. In particular, this work was carried out within the framework of the Spanish project THOFU (Technologies for Hotels of the Future). The main purpose of the project was to propose new solutions for highly sustainable hotels. In this work it is presented the analysis of fusion of several renewable energy systems and energy saving solutions studied or developed in THOFU project.

Because of many possible definitions for near or net zero energy building (IEA-SHC Task 40, 2013; Marszal et al., 2011; Torcellini et al., 2006), the analysis in this paper assumes the global energy demand is a sum of thermal needs for air-conditioning, domestic hot water (DHW) and total electrical demand. Various authors (Gallo et al., 2014; Mohamed et al., 2014; Oliveira Panão et al., 2013) applied this approach to estimate building energy balance. Most of these studies analyze offices and residential buildings. In this work, four hotels with different shapes, climatic conditions and occupancies were simulated to represent the variety of Spanish hotel industry that may serve as a good guide for other Mediterranean countries. In particular, selected hotels referred to urban, rural, mountain and beach typologies. Energy efficiency solutions and renewable energy systems were integrated in the models with an aim of covering the highest

doi:10.18086/eurosun.2014.03.25 Available at http://proceedings.ises.org

amount of demand and minimizing external energy dependence. In order to analyze realistic scenarios, most of the systems included in the model make use of well-known components and technology solutions, though some innovations proposed at the THOFU project have been introduced as well. Hence, considerable energy savings and a good exploitation of renewable energy are desired. Moreover, proposed hotels presented different kinds of services and categories of users. Therefore, different occupancy profiles were defined and analyzed. Simulations were carried out with software TRNSYS®. Only existing code “types” were used to reproduce the components in each subsystem. All the types belong to TRNSYS® basic library and TESS® library.

A detailed description of the analyzed systems is presented in the next section including the specifications of buildings, load demands and energy systems. The following section presents the methodology used to simulate the entire system for each case. Simulation outcomes are shown in section 4 and sensibility analyses complemented the results in order to understand the effects of most important parameters on energy consumptions. Finally, the results are commented in the conclusion and discussion section.

2. System description

In order to evaluate the existing diversity in Spanish hotel industry, four typologies of hotels were modeled with TRNBuild®. Afterwards, buildings performances were analyzed in TRNSYS® Simulation Studio. The analyzed typologies of hotel were beach, rural, urban and mountain. Different shapes, occupancies, climatic data were proposed for each case. Figure 1 (right) shows annual occupancies.

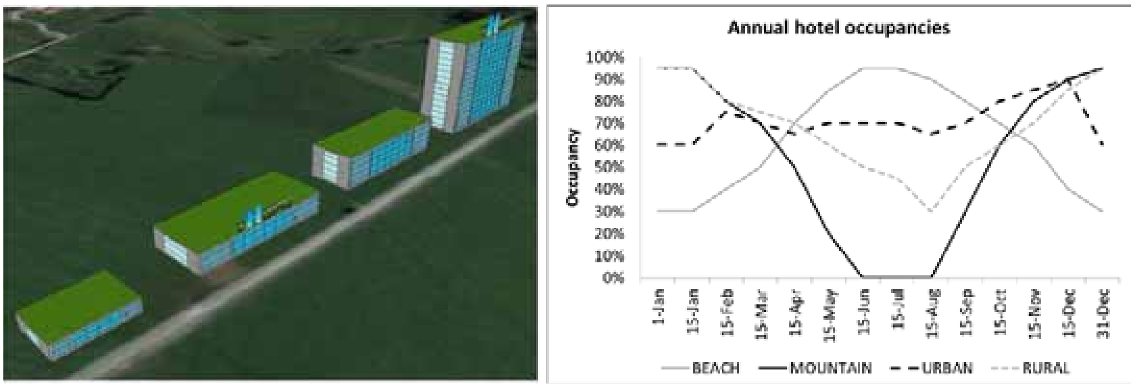

Fig. 1: Models of hotel buildings proposed (left). Occupancy profiles for different types of hotels (right)

Furthermore, six types of service areas were considered: lobby, bar-restaurant, leisure and night entertainment, spa, gym and rooms. Table 1 summarizes principal parameters for proposed scenarios. Because of the lack of climatic data availability for the Spanish mountain location, data from an Italian mountain site were used. For the sake of simplicity, the proposed buildings were divided into three thermal zones, corresponding to different floors and services: spa and gym in the same underground zone, leisure/night entertainment, lobby and bar/restaurant in the same zone at ground floor and the rooms in another zone composed by several floors.

Table 1: Main characteristic for proposed scenarios.

Scenarios	1	2	3	4
Type hotel	Rural	Urban	Beach	Mountain
Site	Santander (E)	Madrid (E)	Almeria (E)	Terminillo (I)
Coordinates	43º27’N, 3º48’E	40º25’N, 3º41’E	36º 50’N,2º 28’W	42º28’N,12º59’W
Climatic zone	Zone C	Zone D	Zone A	Zone E
Size	Small	Tower	Medium	Medium
Floors	3	15	6	4
Surface	30m x 20m	60m x 20m	60m x 20m	60m x 25m
Nr. rooms	37	300	150	100
Capacity	67	600	353	240

Services	Lobby, rooms, bar, restaurants, gym, spa, leisure and night entertainment

Therefore, four different buildings were designed (Fig. 1 left) with a rectangular shape and a roof with ecologic cover (Machado et al., 2000). South façade included water-cooled IntelliGlass® windows (Gimenez Molina, 2011), a double glazing glass with flowing water inside. North façade was fully opaque. East and West façades had 50% opaque surface and 50% windowed. Underground wall had no windows. Table 2 summarizes the adopted values of transmittance and solar factor for wall and window in different climatic zones of Spain, according to current Spanish Technical Building Code (Código Técnico de la Edificación, CTE, 2011).

Table 2: Transmittance [W m^{-2} K^{-1}] of walls and windows utilized in the buildings for different Spanish climate zones and window solar factor.

Orientation	Wall type	Zone A	Zone C	Zone D	Zone E	Solar Factor
North	Opaque façade	0.879	0.703	0.639	0.540	
Est/West	Window	1.770	1.770	1.770	1.770	0.572
	Opaque façade	0.879	0.703	0.639	0.540	
South	IntelliGlass window	5.411	5.411	5.411	5.411	0.380
Roof	Ecological roof	0.203	0.203	0.203	0.203	
Underground	Underground wall	0.540	0.540	0.540	0.540	
	Underground floor	0.523	0.493	0.487	0.480	
Internal	floor	1.404	1.404	1.404	1.404	

In order to cover the global energy demand for each building, an optimized integration of different renewable systems was considered. For each case the same kind of devices were simulated, but with different sizing. Figure 2 shows a simplified flow sheet, similar to the scheme proposed by the authors in a precedent work (Gallo et al., 2014). So, four subsystems were identified: (i) building, occupancy and weather data, (ii) thermal subsystem, (iii) solar domestic hot water subsystem (SDHW) and (iv) electrical subsystem.

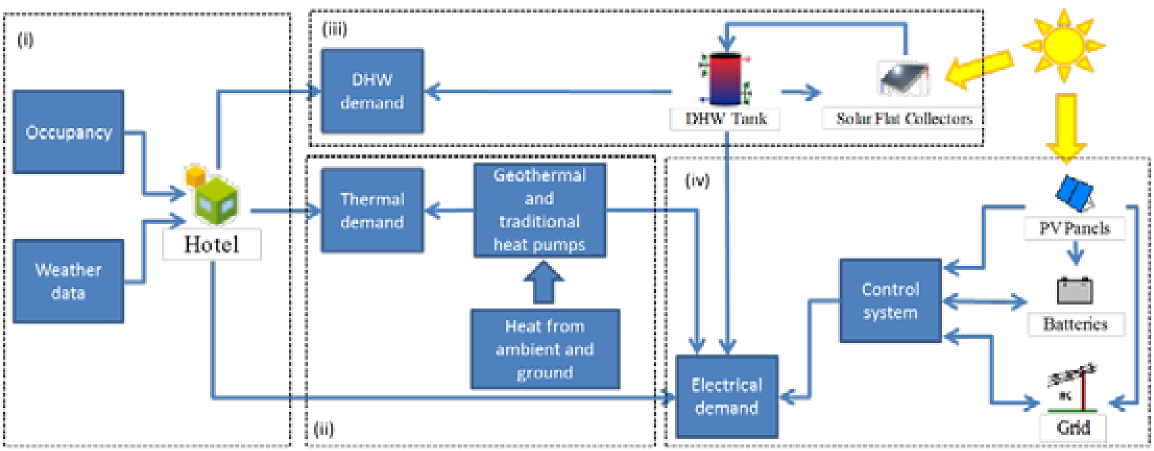

Fig. 2: Simplified flow-sheet and division into four subsystems.

2.1. Building, occupancy and weather data.

In order to simulate building thermal behaviors, the type 56 (multi-zone building) was used. Types 7, 35 and 109 (Meteonorm weather data reader) were implemented in TNRSYS® Simulation Studio to reproduce climate conditions. The hourly occupancy for all hotel services were modeled by using several types 14: thirty normalized hourly occupancies were associated to six services and five categories of users (see figure 3). In order to define the hourly occupancy in each service it was necessary to determine hotel capacity (Ch, see table 1), user category percentage (U_i) and annual occupancy (Oa, see Fig. 1 right). Knowing daily demand (Dd) of electricity or DHW and normalized hourly profile for service (Pn, see Fig. 3) it was possible to calculate hourly consumptions (Dh) for the user category "i" and service "j", as reported in eq. 1:

$$\mathrm{Dh}_{i,j} = \mathrm{Ch}\ \mathrm{Oa}\ \mathrm{U}_i\ \mathrm{Pn}_{i,j}\ \mathrm{Dd}_j \quad \text{(eq. 1)}$$

Total demand is the sum of hourly consumption for each service and user category, as shown in eq. 2:

$$\mathrm{Dh}_{tot} = \mathrm{Ch}\ \mathrm{Oa}\ \sum i \left(\sum j\ \left(\mathrm{U}_i\ \mathrm{Pn}_{i,j}\ \mathrm{Dd}_j\right)\right) \quad \text{(eq. 2).}$$

Through the link between the building, occupancies, and climatic data, the heating and cooling demands were calculated for one-year. Infiltration was considered constant to 0.8 volume/h and ventilation was proportional to occupancy.

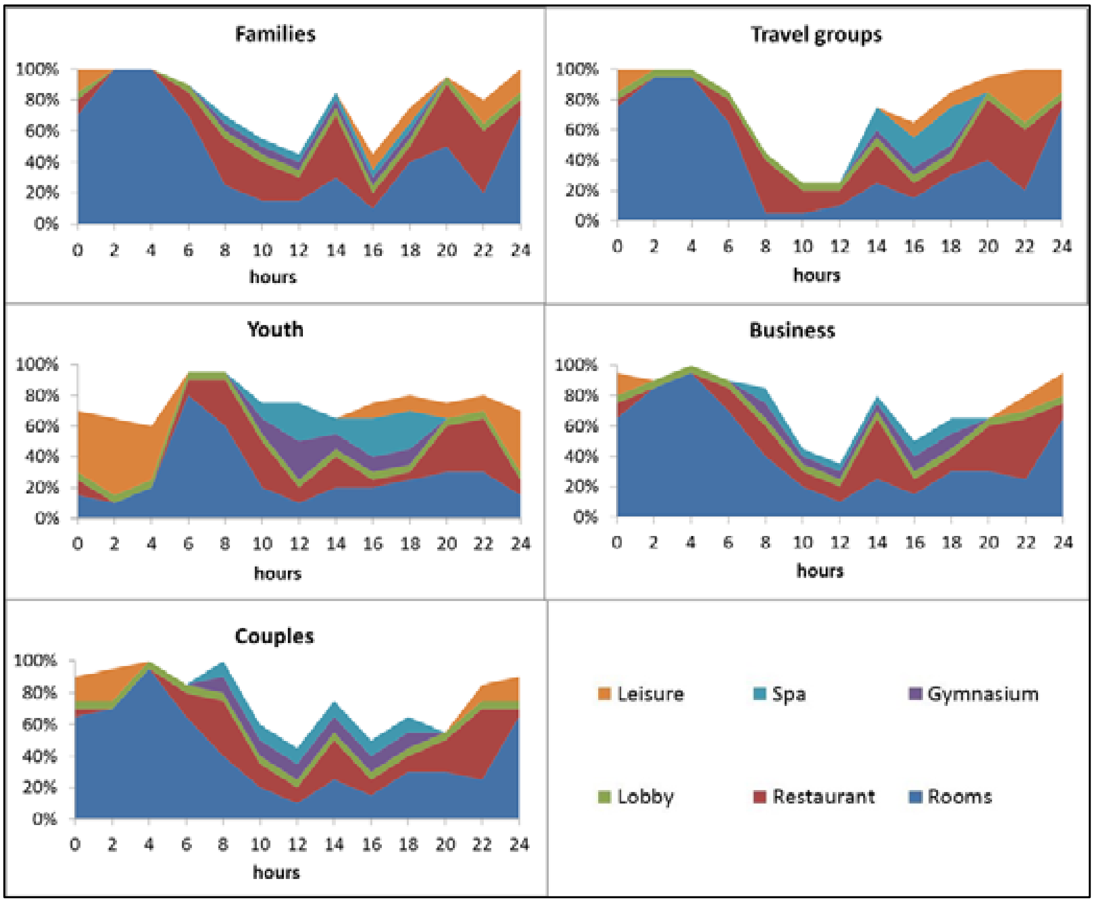

Fig. 3: Hourly occupancy profiles for hotel services and categories of users.

2.2. Thermal system.

Two traditional air-water heat pumps (type 940) and one geothermal water-water heat pump (type 927) composed the thermal system. The traditional heat pumps supplied the thermal needs for underground and ground zones, the geothermal heat pump supplied the room-zone. Traditional air-water heat pumps exchanged heat with ambient air at source side and with water at load side. Afterwards a pump circulated this water into radiant floors inside the building. TRNBuild active layers in underground and ground storeys modeled radiant floors. In a similar way, geothermal heat pump took advantages of ground-heat exchanges to condition air inside rooms. In order to simulate geothermal pile foundations and the exchanged heat between ground and water, a type 557 was used. Some borehole parameters were fixed according to communication with partners involved in THoFu project and according to literature (Sagia and Rakopoulos, 2012; Trillat-Berdal et al., 2007; Yang et al., 2010). Table 3 summarizes those values.

Table 3: Fixed borehole and pile parameters.

Parameter	Value	Unit	Parameter	Value	Unit
Soil thermal conductivity	2.40	$W\ m^{-1}\ K^{-1}$	Borehole radius	0.1016	m
Soil heat capacity	2016	$kJ\ m^{-3}\ K^{-1}$	Inner radius of U tube pipe	0.0200	m
Pipe thermal conductivity	0.42	$W\ m^{-1}\ K^{-1}$	Outer radius of U tube pipe	0.0219	m
Active pile length	40	m	Centre-to-centre half distance	0.0300	m

A TRNBuild active layer, included in the north façade of the building, modeled heat exchanges between water from the geothermal heat pump and air inside the room zone. With the aim of representing an intermittent behavior of the thermal devices, temperature controllers (types 108) activated or deactivated circulation water-pumps (types 114) according to internal zone temperature. This parameter was limited between 20 and 25°C with a tolerance of 2°C.

2.3. Domestic Hot Water System

This subsystem included all the elements to simulate solar domestic hot water (SDHW) system. SDHW plant was composed by solar collectors (Type 1b), a circulation pump (Type 3b), a hot water storage tank with electrical auxiliary resistance, (Type 4c), a temperature-flow control system (Type 2b), a flow-diverter (Type 11b) and a T-piece mixer (Type 11h). The domestic hot water demand was proportional to the occupancy in each hotel service (see figure 3). Therefore, adding the demand for each service and category of users, total DHW consumption was estimated.

2.4 Electrical System

A photovoltaic plant (type 180), lead-acid batteries (type 47), inverter-load controller (type 48) and a weather data reader (type 109-TMY2) formed the scheme of the electrical system. Type 180 could read an external file with personalized PV panel parameters. Parameters from Conergy PowerPlus 250P data-sheet were used to simulate the photovoltaic plant. One optimized inclination and orientation for all the PV panels was considered for each location. In battery type, the connected modular cells were simulated in order to reach their desired storage capacity, but the voltage effect was neglected. In type 48, an intermediate level between the minimum and the maximum battery charge was defined in order to control the electricity flow from the PV. If such a level were reached, load controller would allow the PV to feed load directly. Electricity exchanges with the grid were allowed and the grid was considered as an infinite source or sink, yet the battery charge directly from the grid was not permitted. The electrical demand was the sum of different components. For each service a constant and a variable demand were assigned depending on occupancy. In addition to these, the electrical consumption from heat pumps, circulating pumps and from auxiliary resistance in DHW tank was summed too.

3. Methodology

Sizing all the devices included in the flow-sheet was essential for a good simulation. Because of the large number of parameters and inputs, an iterative process was conducted with the aim of achieving feasible results in the modeled subsystems. A first annual simulation was run to define the thermal demands and check if the SDHW system working. In order to determine the heating and cooling demands, the set point temperatures were fixed to 20 and 25°C, respectively. The parameters in SDHW system were varied, until the minimum solar contribution for the considered location was reached, according to the restrictions defined in the Spanish Building Technical Code (CTE, 2009). Afterwards the size of the thermal system was carried out and included in the model. Regarding the heat pumps sizing, the maximum heating and cooling power demands were calculated. Therefore, to avoid oversizing, only 70% of maximum powers were covered. The rated heat pump performance coefficients (COP) were assumed equal to 4. Hence, another run was required to determine the global electrical demand. At that moment, the PV-battery system was sized to cover 50% of the annual electrical demand, with the exception of the case of the mountain, in which only 25% of the demand was covered. Thus, the last simulation was run to collect and to analyze the results.

Then, the sensitivity analysis was carried out to define the dependence of the thermal behavior on the occupancy and the set point temperatures. Finally, the parametric analysis for PV system was conducted. This analysis followed the methodology proposed by different authors in literature (Gallo et al., 2014; Matallanas and Monasterio, 2011; Téllez-Molina and Prodanovic, 2013): three parameters (self-consumption SC, capacity fraction CF and load fraction LF) were analyzed to evaluate self-consumption, total production and load coverage:

$$SC = \frac{E_{PV,load} + E_{bat,load}}{E_{PV}} \; ; CF = \frac{E_{PV}}{E_{load}} \; ; LF = \frac{E_{PV,load} + E_{bat,load}}{E_{load}} = SC \cdot CF \quad \text{(eq. 3)}$$

Where $E_{PV,load}$ is the annual PV electricity feeding the loads, $E_{bat,load}$ is the annual electricity feeding the load from batteries, E_{PV} is the annual electricity produced by PV array, E_{load} is the annual electricity consumed by the load. The first parameter (SC) represents the energy produced by the PV array and instantaneously consumed, the CF is an indicator of PV array dimensions and LF represents the part of the load covered by solar energy from the PV system or from batteries. Therefore, as mentioned before, for the reference cases the PV size corresponded to CF=0.5 with the exception of mountain case, in which CF was 0.25.

4. Results

To evaluate the building thermal energy demand, the obtained results were compared with the values presented in the IDAE report (IDAE-Aiguasol, 2011), where several types of the existent Spanish buildings were simulated by using TRNSYS®. According to the project objectives, the simulated hotels demonstrated lower thermal demand than the existing buildings. Table 4 resumes most important results for each location. The values for the thermal requirements are expressed in energy per surface unit.

Table 4: Main results for analyzed locations.

Location	Heating demand [kWh m^{-2}]	Cooling demand [kWh m^{-2}]	Solar contribution in DHW	PV power [kW] (kWh kWp^{-1})	PV to load, PV to battery, PV to grid
Santander	24.52	0.32	71%	150 (1028)	53%, 14%, 33%
Madrid	20.19	1.45	72%	666 (1320)	55%, 35%, 10%
Almeria	3.70	3.00	73%	336 (1356)	60%, 16%, 24%
Terminillo	75.60	0.00	65%	156 (1155)	64%, 14%, 22%

The solar contribution in DHW demand represents the saved energy from the use of the solar thermal collectors. The auxiliary electrical resistive heaters supply the remaining DHW demand. The obtained values meet the Spanish normative. In the fifth column of table 4, PV power represents the total panel power peak of the installation, while values in brackets represent the specific annual production for considered arrays. Finally, the last column includes the annual share of the PV production.

In order to evaluate the effect of different user categories on the hotel electrical demand, the sensitivity analysis was carried out, changing the mix of the occupancy user typology. Table 5 shows the results for the smallest hotel (Santander). Consumption variation is always lower than 2.62% compared to the reference case (case 1). For the other hotels, the amount of the electrical consumption was mostly independent of the occupancy. Therefore, the demand variation with the user mix was found negligible.

Table 5: Sensitivity analysis.

Case	Family	Youth	Business	Couple	Travel group	Consumptions Variation
1	20	20	20	20	20	0,00%
2	0	0	70	0	30	-2,48%
3	33	33	0	0	34	-0,55%
4	50	50	0	0	0	-1,68%
5	50	0	0	0	50	-1,93%
6	0	50	0	0	50	-1,75%
7	0	0	0	0	100	-2,61%
8	100	0	0	0	0	-2,62%
9	0	100	0	0	0	-2,10%

In order to evaluate the variation of the thermal energy demand with the set point temperature, the sensitivity analysis was applied to the Spanish test cases. Figure 4 shows the results: heating and cooling were analyzed independently. In Figure 4a) the heating specific thermal demands are plotted and in Figure 4b) the same demands are compared with the reference cases at 20°C. A similar analysis was carried out in Figures 4c) and 4d) for the cooling demand considering the set point temperature at 25°C, as the reference case. For the simulated cases, the set point temperature has a significant impact and approximately 20% of the heating consumption can be reduced if the set point temperature is reduced for just 1°C. For the cooling, the savings are even higher if the set temperature is increased. The Santander case did not present any cooling demand.

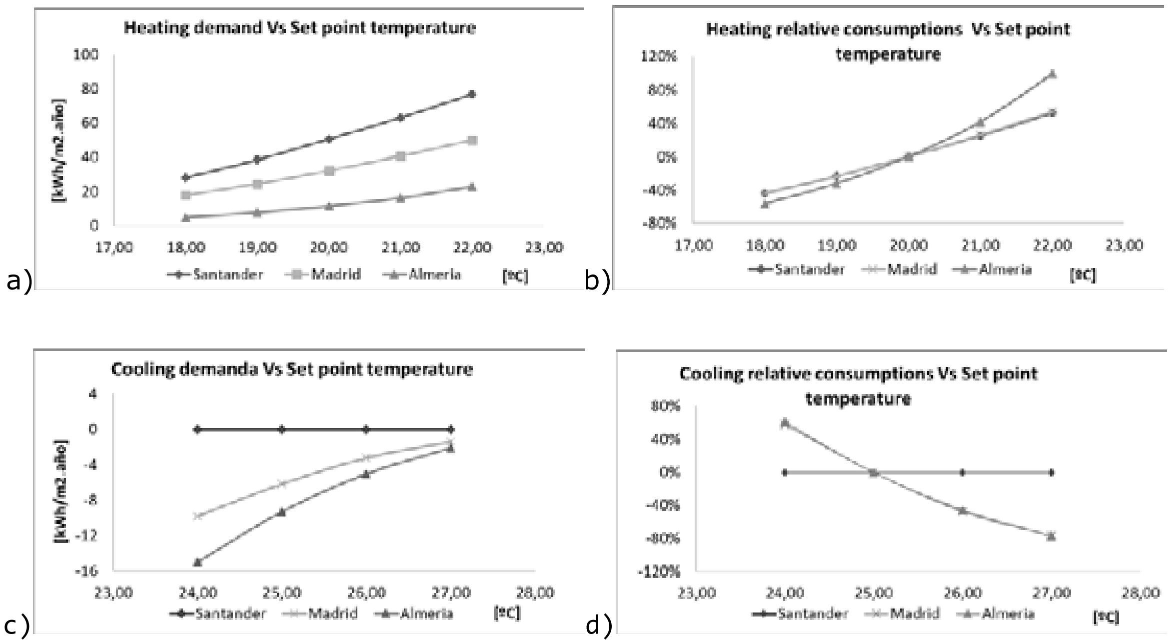

Fig. 4: Sensitivity analysis. Total (a) and relative (b) heating consumptions and total (c) and relative (d) cooling consumptions with set point temperature.

Finally, the parametric analysis was conducted to evaluate the electrical system: LF, SC and CF where changed as a function of the installed PV power and daily battery storage capacity. Therefore, the size of PV array was varied in order to achieve CF factors equal to 0, 0.5, 1, 1.5 and 2. In particular, in Figure 5 are plotted the results for the three Spanish locations, considering the storage capacity equal to 25% and 50% of the mean electrical daily demand. The storage capacity was also modified by changing the number of battery cells installed. In Figure 4d, the product of SC and LF is plotted for Almeria case. The maximum is achieved for the values of CF between 0.5 and 1, and the maximum moves towards CF = 1, towards increasing the storage capacity. CF=1 means that annual energy production of PV system is equal to the annual electrical load and SC is equal to LF.

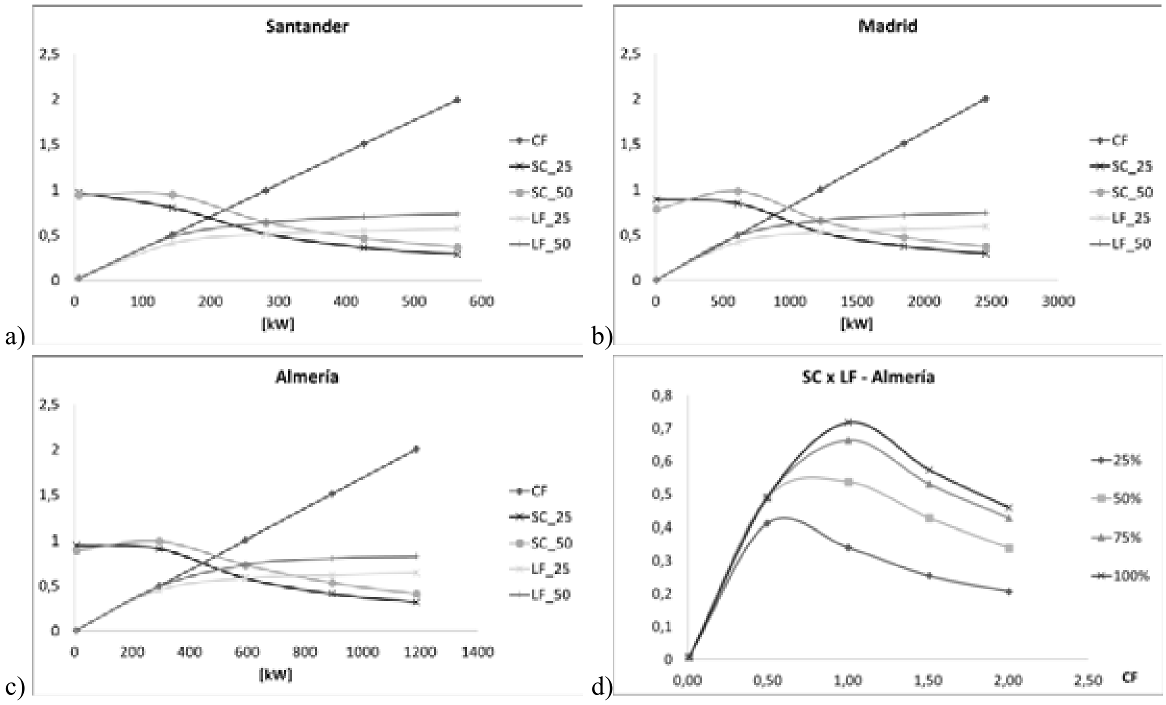

Fig. 5: Parametric analysis. Variation of CF, SC, LF with installed PV power and daily battery storage capacity.

5. Discussion and conclusions

Four different configurations of buildings have been developed with the integration of several renewable energy technologies (geothermal active pile foundations, Intelliglass® window, solar PV and solar thermal). The proposed schemes represent high-energy savings for decarbonized hotels. Main results are:

- Important energy savings can be achieved for thermal demands. In all the cases, the values obtained for the hotels are above what is established by Directives for existing buildings in Spain.

- Examples analyzed for hotels in Spain demonstrate that it is possible to make use of solar energy as main energy source. Systems were sized to meet 70% of DWH demand and it was possible to cover all power demand with the proposed options. In particular, it is possible to supply 50% of the total energy with the PV panels that is a value well above the objectives set by the European Union under the program 20-20-20.

- Simulations performed demonstrate that the use of geothermal heat pumps can be a good option when applied to radiant panels. In the event of a high heating demand, an auxiliary system would be required.

- The variation of the temperature set point has a significant effect on the thermal demand of the building, both for heating and cooling. Variations of up to 40% were obtained for the thermal consumption for each degree of the temperature set point. By introducing variable profiles for the temperature set point along the day it is possible to achieve significant energy savings without affecting comfort, in particular during cold seasons.

- For the analyzed cases, the variation of user mix does not have a significant impact on the global consumptions

- All the climatic zones analyzed achieve degrees of autonomy higher than 60% (Load Fraction) with the capacity fraction of 1 and the capacity of daily storage of 50%.

- Best values, in terms of the photovoltaic self-consumptions and load fraction, were achieved for the beach hotel that was located in Almeria, because of the highest solar radiation.

- Technical sizing of the PV system should lead to a capacity factor of 1 so that the self-consumption and the coverage ratio are jointly optimized, in such a way that oversizing of the plant is avoided and a good autonomy of the electrical system is achieved, according to the European objectives for 2020.

6. Aknowledgments

The authors would like to thank “Centro para el Desarrollo Tecnológico Industrial (Centre for Industrial Technologic Development) – CDTI” and “Ministerio of Ciencia and Innovación” for their financial support to THoFu. (Tecnologías del Hotel del Futuro) project.

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