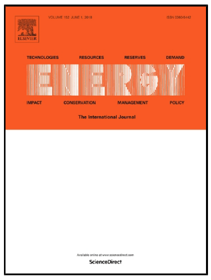

Analysis of some renewable energy uses and demand side measures for hotels on small Mediterranean islands: a case study

M. Beccali, P. Finocchiaro, M.G. Ippolito, G. Leone, D. Panno, G. Zizzo

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Analysis of some renewable energy uses and demand side measures for hotels on small Mediterranean islands: a case study.

M. Beccali*[1], P. Finocchiaro[2], M.G. Ippolito[1], G. Leone[1], D. Panno[1], G. Zizzo[1]
* Corresponding author. Email: marco.beccali@unipa.it
[1]Dpt. of Energy, Information Engineering and Mathematical Models, University of Palermo, Viale delle Scienze, Building no. 9, 90128 Palermo, Italy;
[2] SolarInvent s.r.l., via Giacomo Leopardi 16/A, 95030 Mascalucia, Italy.

Email addresses: pietro.finocchiaro@solarinvent.com, marianogiuseppe.ippolito@unipa.it, giuliana.leone@dream.unipa.it, domenico.panno@unipa.it, gaetano.zizzo@unipa.it

ABSTRACT

Tourist activity strongly influences the energy consumption and the overall load profile of communities with isolated energy systems. One example is hotel sectors on small islands that are not connected to mainland energy distribution grids. The use of solar energy systems could be a smart option for reducing energy consumption and tackling seasonal fluctuation. The operation of a weak and isolated electric grid requires attention to the management of power profiles in very short time frames. Energy storage (thermal or electric), as well as building automation control technologies, can be utilised for these aims. In this context, the present paper illustrates a study conducted at a hotel located on Lampedusa Island (Italy) that was considering some energy-retrofit scenarios dealing with the exploitation of renewable energy sources and building automation control technologies. The hotel is equipped with an air-to-water heat pump able to fulfil air conditioning and domestic hot water demands. Data concerning the hotel's energy consumption was measured during summer months while yearly data was provided by the local electric utility company. Detailed simulation models have been validated by this data and used to assess the efficacy of retrofit scenarios and their effects on the average daily electric profile.

KEYWORDS

BAC, RES, TRNSYS, energy saving, hotels, small islands.

1. INTRODUCTION

The majority of the small islands in the Mediterranean basin are not connected to the mainland's electric grid nor to natural gas pipelines. Consequently, most of the islands' energy needs, including heat, are fulfilled by electric devices [1] fed by local thermal power plants. In addition, these plants mainly rely on imported fossil fuels. The increase in oil prices and the increased attention on emissions mitigation strategies make this kind of energy system unsustainable at socioeconomic and environmental levels. In order to overcome these issues, it is advisable to increase use of local renewable energy sources (RES) in order to enhance energy efficiency and to implement flexibility and resilience on the electricity generation-distribution-use chain. One option that's been investigated is increasing the efficiency of existing traditional thermal power plants by retrofit actions, enabling combined heat and power (CHP) plants, and constructing district heating/cooling networks [2]. Nevertheless, studies conducted on six Italian islands demonstrated that CHP technology is only moderately economically attractive when public economic support mechanisms exist. Better results are achieved when hybrid renewable poly-generation systems are considered, but once again, huge

investments are needed. Indeed, the economic attractiveness is related to the linear density of the energy demand, and to the fact that the majority of the energy available for heating and cooling purposes is currently used [3]. For example, 8.5 years of simple payback time can be achieved on Pantelleria, assuming use of a multipurpose system connected to a district heating and cooling network and driven by geothermal and solar sources. The described plant is capable of covering the electricity and heat demands of a small community and, at the same time, covering the fresh water demand of the island [4]. Other authors investigated the possibility of integrating energy and water supply systems so that excess wind power production could be used in desalination units to supply fresh water on demand [5]. The goal of such a system is to use desalinated water in a pumped hydro system to store the extra-produced power from wind and fulfil the gap between intermittence RES production and island energy demand.
However, on many isolated islands, the percentage of RES plants compared to total electricity production is generally close to 0% [6], even if several options are available within the territory. Erdinc et al. [7] critically examined RES integration opportunities on different small islands, focusing on solar, wind, wave, geothermal, biomass, and hydroelectric energy generation that could be easily applied. They recommend attention be paid to demand side strategies that represent a viable chance for RES penetration of a small-scale grids. Other researchers have pointed out that a SWOT (strengths, weaknesses, opportunities, and threats) analysis could help to address institutional, organisational, and habitual problems that usually inhibit sustainable strategies and solutions application [8]. In this regard, Northern Cyprus was one of the first countries to encourage the use of solar water heaters. This effort resulted in widespread installation of such water heaters in single-family houses and led to a maximum yearly saving of 72 GWh of primary energy [9]. Recently, Neves et al. [10] proposed a characterisation of island energy-load based on economic, demographic, and cultural criteria. Their study highlighted how islands with the highest demand per capita are generally located in developed countries, and all have tourist activities that strongly influence energy consumption and the load profile of the island itself. In this regard, Polanco and Yousif [11] analysed energy consumption in the hotel sector in Gozo (Malta), recognising its impact on the island's energy load curve. They also identified the main energy-consuming activities in a typical Mediterranean hotel in order to prioritise energy retrofit activities. Small Italian islands could easily be included in the category proposed by Neves et al., and show similar energy consumption as proposed by Polanco and Yousef and as demonstrated by Beccali et al. [12].
Moreover, Ciriminna et al. [13] identified some critical barriers to significant penetration of renewable energy in the Sicilian islands. These barriers are mainly related to local regulations and landscape management that usually forbid RES large-scale plant installations. In such an isolated context, reduction of the energy demand by end users is needed, and retrofit actions at building level have to be prioritized. Indeed, it has been demonstrated how typical Italian residential buildings in warm climates—such as the one of Palermo—could reduce their energy needs by addressing maintenance work at building envelopes and thermal plant levels [14]. Similar results could be achieved in tertiary stock by applying mitigation strategies. Indeed, well-proven technological solutions for energy retrofit are actually available in the market and have been shown to be useful in order to reach the Net Zero Energy Building (NZEB) target [15], even if a critical barrier still exists at an economical level [16]. Studies have demonstrated how domestic solar hot water systems [17], solar assisted heat pump s[18], and solar desiccant evaporative cycle (DEC) systems [19] are viable options at a building level to directly exploit renewable energy sources and significantly reduce electricity demands. Other studies focused on the use of information and communication technologies (ICT) [20], demand side management (DSM) strategies [21], and building automation control (BAC) technologies [22]—with specific regard to household appliances [23]—that could easily be used to reduce building energy consumption while managing the effects on the electric distribution grid.
Di Silvestre et al. [24] specifically addresses DSM on the small Italian island of Lampedusa. Their study demonstrates how the installation of a distributed photovoltaic (PV) generation system could lead to substantial benefits in terms of investment payback, voltage drop, and emissions reduction.

Finally, the present work relies on previous studies [25] in which energy consumption of small isolated islands in the Mediterranean basin has been estimated by end users and allocated with respect to the employed energy carriers [26]. The present work focuses on a simulation of several energy retrofit scenarios at building level for a typical hotel on the island of Lampedusa. The hotel in this study is equipped with an air-to-water heat pump able to fulfil air conditioning and domestic hot water demands. This paper is structured in three sections:

- Section 2 describes the methodology adopted for the present study, the hotel's characteristics, and the hypothesised future scenarios.
- Section 3 shows the results of the performed analysis in terms of energy savings and modification of the daily electric load profile of the hotel.
- Section 4 summarizes the work.

Demand side management (DSM), renewable energy sources (RES) and building automation control (BAC) technologies have been considered in Section 2, while results from simulation models (validated using data provided by the local electric utility) are presented in Section 3.

2. METHODS

The present work aims to evaluate energy retrofit scenarios specifically chosen according to building architectonical and plant features. The proposed methodology follows the flow chart in **Figure 1**. The first step involves selecting a representative user to be analyzed according to well-chosen criteria based on the analysis of statistical data. In the official data collected by the National Institute of Statistics [27], number of guest rooms and by star classifications—is useful in determining the size and the quality of the most diffuse hotel in the small islands. Whenever available, further specific data is desirable in order to better define a representative user in the specific context of small islands. Consequently, the present work is also based on the results of a questionnaire campaign conducted on Lampedusa concerning plant and electrical end user equipment [1].

Once the selection criteria are established, it is possible to look for a representative building among the island hotels. At that point, on-site surveys are useful for determining hotel-specific architectonical and plant features well-suited to the simulation model. The present methodology plans to use easily obtained monthly electricity consumption data provided by the local utility provider in order to validate the simulation model on the actual hotel configuration. To further check the reliability of the validated models, data from experimental campaigns has also been considered. Monthly and hourly energy demand profiles are the main target of this validation procedure. According to the state of the art technology and considering local restrictions and specific technical issues, retrofit scenarios are identified and simulated. Results from the actual hotel simulation model and from the retrofit scenario models have been acquired and compared in order to evaluate their impact on the daily hotel electric load profile.

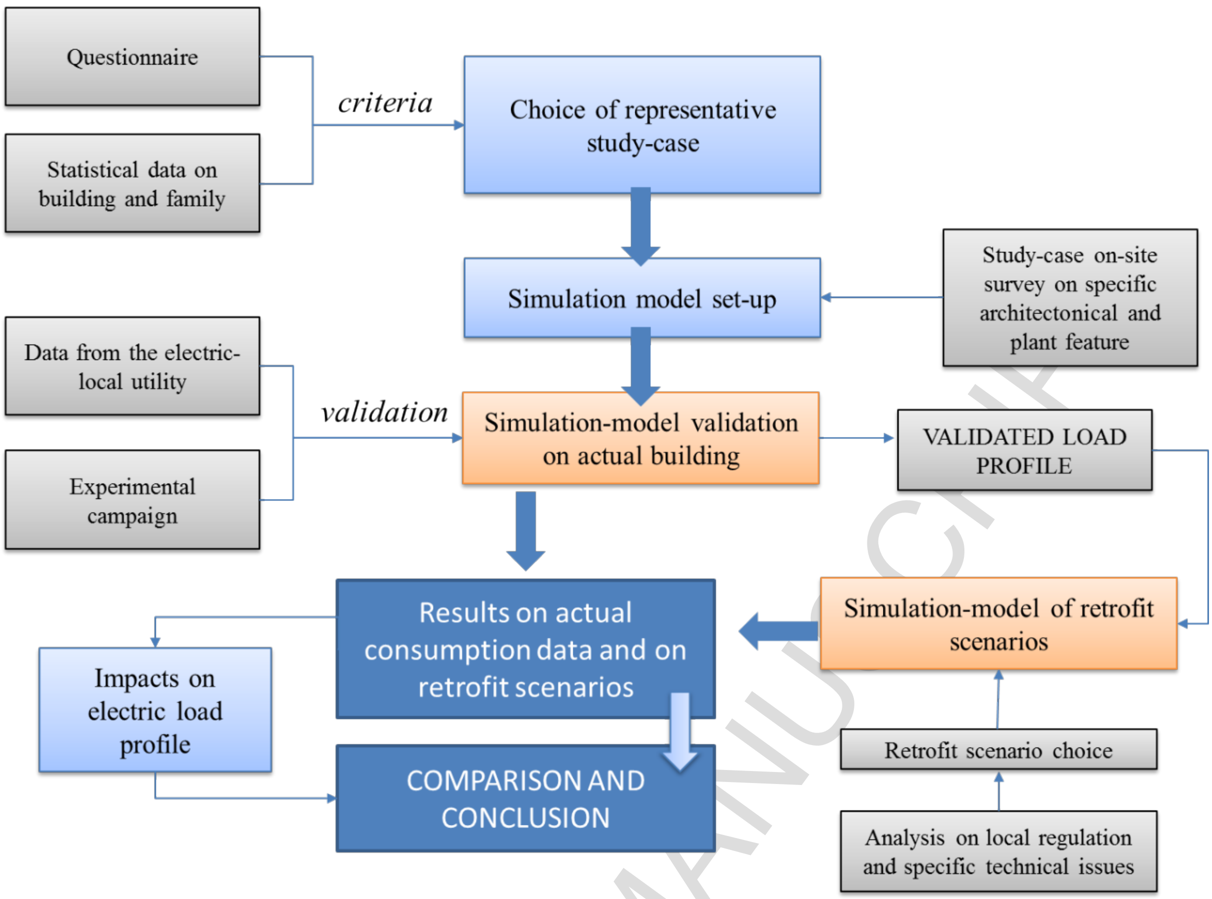


Figure 1. Workflow of the method.

3. CASE STUDY: Hotel characteristics

According to the previously-stated criteria, the most common hotel configuration in small Italian islands is a 3-4 star hotel (57%), built in the 1990s with approximately 20 guest rooms [27]. The questionnaire campaign [1] reveals that thermal needs of hotels in Lampedusa are mostly fulfilled by heat pump systems. Solar thermal equipment is common, while photovoltaic plants are infrequent. Lighting systems rely on halogen lamps but no building automation control is provided.
A representative hotel in Lampedusa was then chosen, and data regarding the electric equipment and building characteristics of the hotel was collected via an onsite survey. The chosen hotel, represented in **Figure 2**, is a typical two-story, built in the 1990s with 20 guest rooms. Common spaces are located at the ground floor and include reception, restaurant, kitchen, offices, and living rooms. The building footprint is roughly rectangular; the major side is 40 m long, east/west oriented. The envelope-surface to heated-volume ratio is 0.51, while the ratio of the total glazed area to the façade area is 0.25 for the west orientation and 0.17 for the east orientation. Representative average values for the thermal conductance U-value of external walls, roof, and the ground floor have been calculated on the basis of the characteristics of the building envelope and are equal to 2.45, 1.26 and 1.13 W/(m^{2}K), respectively. The hotel's yearly electricity consumption is 4,213 kWh/beds, which is equal to 92% of the average value for other Lampedusa hotels.

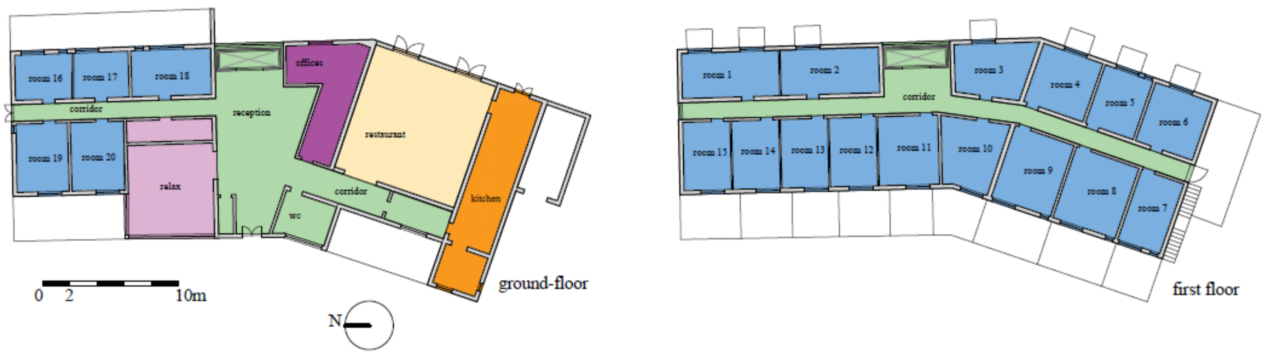


Figure 2. Plans of the hotel with thermal zone highlighted by colors.

An air-to-water heat pump water heater (HPWH), whose main characteristics are reported in **Table 1**, fulfills the heating/cooling (H/C) and domestic hot water (DHW) demands. Two electric meters (hereby addressed as El.M._1 and El.M_2) have been installed on the two switchboards, providing electricity respectively to the HPWH (33 kW power capacity) and to the rest of the electric loads (31 kW power capacity).

Table 1. Heat Pump Water Heater characteristics.

HPWH	H/C Power [kW]	Electricity consumption [kW]	EER/COP [kW/kW]
Cooling	73.3	27.6	2.66
Heating	83.1	26.3	3.16

Moreover, the on-site survey was useful for characterizing the electrical equipment and the lighting system of the hotel. The lighting system is 100% halogen lamps, and only one occupancy sensor is installed in the lobby. Refrigerators and televisions are present in every guest room.

Monthly electricity consumption data was provided for both meters by the local utility (SE.LI.S. Spa) and is summarized in **Figure 3**. Data for three pricing period is labeled as F1, F2 and F3. According to Italian legislation, the F1 period includes all work day hours from 8:00 a.m. to 7:00 p.m.; F3 comprises holidays and hours in work day hours from 11:00 p.m. to 7:00 a.m.; F2 comprises all remaining hours in a week. Distribution of energy consumption across the three periods was similar for each bi-monthly revenue period for both meters. The highest consumption—42% of the total consumption—was recorded in the F3 period, while 33% of consumption took place in F1 and 25% in F2.

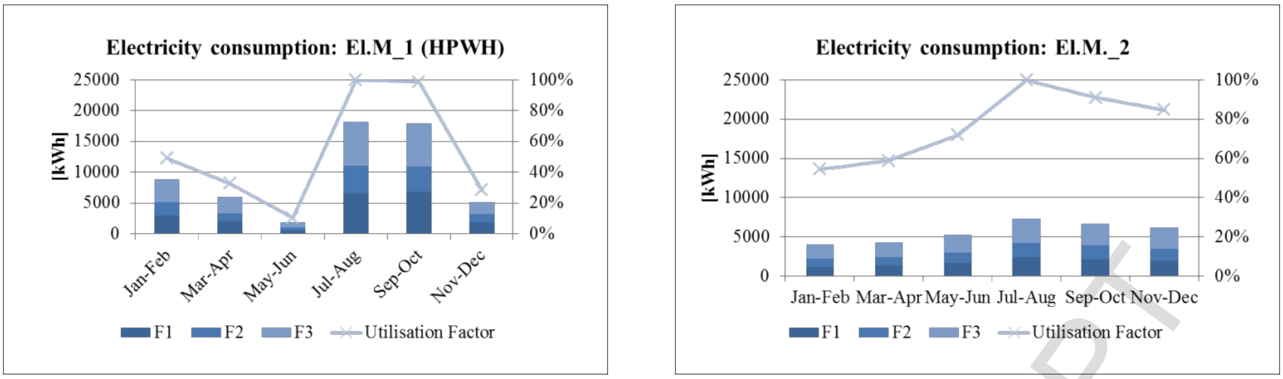


Figure 3. Hotel electricity consumption, data provided by SE.LI.S.

The measurement campaign took place from April to June 2016 and focused on the HPWH operation mode (**Figure 4**). A smart meter was installed in the main switchboard of the El.M_1 and measures total energy consumption of the HPWH every five minutes. The data acquired through these measurements confirms the average energy consumption trend shown in the energy bills for the sole HPWH (**Figure 3**).

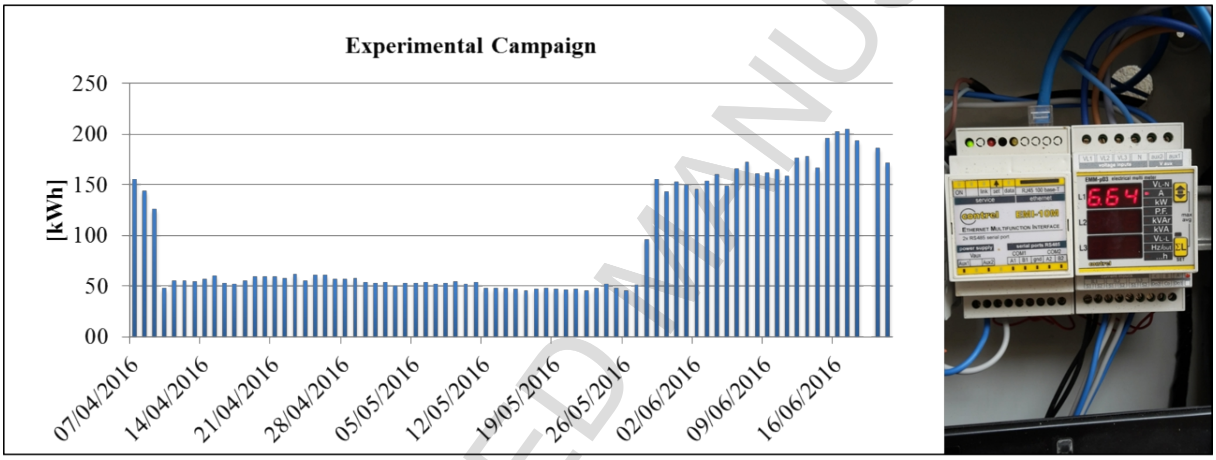


Figure 4. Electricity consumption survey and picture of the smart meter.

3.1 Simulation models

A TRNSYS model has been created to simulate the actual energy consumption of the hotel and to predict the energy retrofit potentialities related to RES integration and to the application of BAC technologies. The model is based on different thermal zones, as shown in **Figure 2**, and includes detailed macros on HPWH operation. The model also includes the lighting system and other electric appliances whose characteristics were collected during the on-site survey. Occupational schedules have been carefully assumed, as they are a crucial factor in the simulation.

Based on the understanding that electricity consumption is higher when hotel occupancy is higher, data shown in **Figure 3** was useful in determining monthly and hourly utilization factors. On a yearly basis, a utilization factor is applied month by month and is calculated as the ratio between energy consumption in a bi-monthly billing period and the highest recorded value in the July-August billing period. In the same way, daily occupational schedules were based on the energy consumption distribution across the three time periods (F1, F2 and F3).

Figure 5 schematically shows the HPWH operation. Three energy storage tanks are connected to the HPWH, and each is dedicated to a specific purpose: cooling, heating, or DHW needs. This set-up was simulated using a macro in TRNSYS. Type 4 is used for simulating energy tank behavior, type 941 for the HPWH, and a series of thermostat and controller types are used for managing the HPWH functioning mode. Type 941 is useful for determining power input (including compressor and auxiliaries consumption) and heat transfer rates within the cycle. In cooling mode, rejected heat from the condenser is directly used for DHW production, while in heating mode, priority logic is established so that DHW demand is fulfilled first whenever necessary.

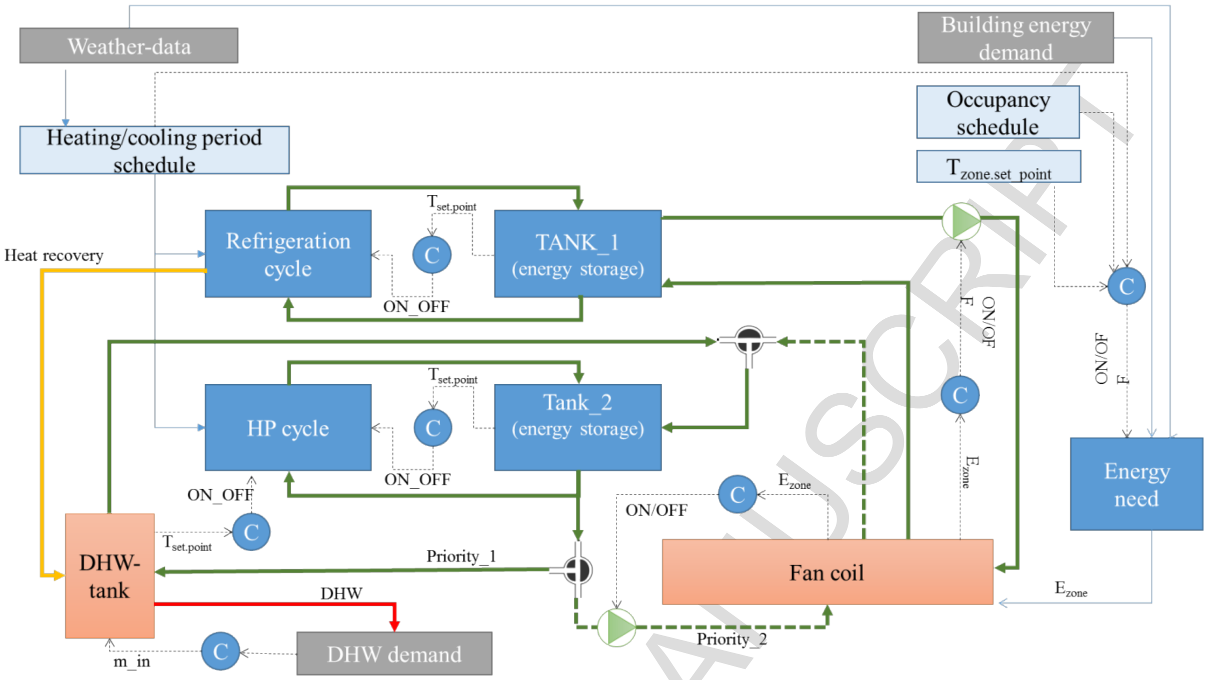


Figure 5. HPWH simulation scheme.

Another macro was utilized for type 272 to determine light consumption for each thermal zone. Type 272 requires installed power and two control inputs (one for occupancy and one for daylight factor control). In order to simulate actual hotel settings, the on-spot detected installed power was introduced first, and only occupancy control was considered.
Similarly, typical hourly energy consumption values for appliances in the hotel were used as reference to determine real hotel appliance equipment consumption hour-by-hour [23], **Figure 6**.

fridge	204	-	204	-	204	-	204	664	664	-	-	204	664	664	-	204	-	204	1,329	332	332	-	204	-
tv	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	400	2,400	2,400	2,000	-	-
led	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320	320
washing machine	-	-	-	-	-	-	-	-	1,533	300	-	-	-	-	-	-	-	-	-	-	-	-	-	-
coffee machine							2,000	2,000	2,000					2,000										
ice-box	107	-	107	-	107	-	107	347	347	-	-	107	347	347	-	107	-	107	693	173	173	-	107	-
autoclave	250	250	250	250	250	250	250	250	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000

Figure 6. Hourly consumption of main appliances in the studied hotel.

Finally, data in Figure 3 was suitable for validating the simulation model, with the relative error between real and simulation data ranging from +5% to -5%.

3.2 Energy-retrofit scenarios

According to actual energy used, four assumed energy retrofit scenarios were investigated:

- **Scenario 1:** installation of a solar thermal (ST) collector for DHW production coupled with the HPWH;
- **Scenario 2:** installation of an air handling unit (AHU) based on a dessicant evaporative cooling (DEC) system coupled with an ST collector;
- **Scenario 3:** installation of a 30 kWp photovoltaic (PV) plant for on-site production, with or without electric storage, coupled with the HPWH;

- **Scenario 4:** replacement of the existing lighting system with a new LED-based system, with and without ON/OFF controls, and optional BAC control system for other loads.

These theoretical scenarios take into account local regulations that promote the use of solar thermal plants, nonetheless, a PV system has been considered in Scenario 3 as an option in order to evaluate and compare its energy benefit with the energy benefit ensured by permitted technologies. The first two scenarios use solar thermal plants for DHW production and for driving a desiccant evaporative cooling system, while the last scenario proposes a zero-impact strategy at a landscape level.

3.1.1 Scenario 1. Solar thermal collector for domestic hot water production

In Scenario 1, a forced circulation loop, in combination with a water tank with an internal heat exchanger, was considered in the TRNSYS project for the solar system. The collection features of such a system are shown in **Table 2**. The pump is controlled by a differential thermostat, which detects temperature differences between the solar collector's outlet and the bottom of the tank with a hysteresis of 5 degrees.

Table 2. Solar Thermal Collector technical features.

Total area	8,8 m^2
Aperture	7.05 m^2
Volume	7.19 l
Weight	186 kg
Conversion factor	0.689
Test flow rate	200 kg/h
Loss coefficient	3.85 W/m^2K

2.1.1. Scenario 2. Dessicant evaporative cooling system

In Scenario 2, the system configuration incorporates a DEC AHU with ST collectors (280 m^2) that are also used for DHW production. In this theoretical scenario, the ST collectors were installed on the roof of the hotel, which has a total surface of about 350 m^2.

In the TRNSYS simulations, the currently installed heat pump was considered a back up source for both summer and winter. In winter, the DEC system contributes to heating the building by supplying warm air heated by the ST collectors.

The solar DEC AHU, which has a maximum flow rate of 12500 m^3/h, operates according to the *freescoo* concept [28] based on its new configuration [29]. The system is based on an innovative and patented DEC open cycle technology: by using low enthalpy heat from solar thermal collectors and water evaporation, *freescoo* directly handles external hot and wet air to create a conditioned stream typically at 18-20°C and 50-60% relative humidity, drastically reducing electrical demand in comparison to conventional HVAC systems. It is mainly based on two processes:

- Physical water adsorption that reduces the moisture content of external air up to the desired humidity rate by using two cooled package beds of silica gel in a batch process. Each adsorption bed is realized with an air to water heat exchanger filled with silica gel grains. The refrigerant used in the process is water; the adsorption material is cooled by water that flows through the tubes, and a dry cooler is used to reject the adsorption heat generated by the desiccant bed operating in dehumidification mode. After hours of working, the adsorption sorbent material reaches its maximum moisture content, and has to be regenerated by heating and drying the sorbent material with hot air.
- The evaporative cooling process takes advantage of advanced double stages indirect evaporative coolers, which reduce air temperature up to the supply conditions without increasing the humidity content.

The simulation model also incorporated hot water production, with a water tank of 4.5 m^3. The characteristics of the ST collectors are similar to the ones already mentioned, except that the slope is now 25° to minimize visual impact.

2.1.2. Scenario 3. Photovoltaic system

The performance of a PV system with a peak power of 30 kW_p was investigated by SAM software [30], and the results were compared to the electrical consumption calculated by the TRNSYS model. This hypothetical plant can generate an amount of electricity (47409 kWh) just below the annual energy demand of the heat pump (54874 kWh). The purpose of the PV plant is to assist the heat pump by maximizing self-consumption, reducing consumer demand for electricity and delivering surplus energy. The different nature of the examined electrical load compared to the residential case study should be emphasized. It follows that the aforementioned goals are particularly hard to achieve because the electric load is extremely variable, both on a monthly (with very limited energy demands in winter, spring, and autumn, and very large energy demand in the summer) and hourly basis. In fact, although there are thermal storages (cold/hot and DHW), the on/off cycles of the heat pump last 5-6 minutes. Finally, the introduction of an electrical storage system was assumed: its capacity was subject to a specific parametric study.

2.1.3. Scenario 4. Bulding automation control system

This scenario relies on the reference TRNSYS model and focuses on the BAC and re-lumping retrofit strategies according to the following sub-section:

- Scenario LED: the existing halogen lamps are replaced by more efficient LED ones.
- Scenario LED+Ctrl: a control strategy based on the illuminance values in the room is introduced in type 272.
- Scenario BAC: a control strategy for the appliances is introduced and hourly consumption of main appliances is calculated accordingly.

In the LED scenario, the luminaires power was evaluated taking into account the recommended value of illuminance for a specific visual task by UNI EN 12464 [31], according to the following equation:

$$P_{W\text{-}zone} = \Phi_{lum,zone}/\Phi_{lum,lamp}\ P_{W,lamp}\ FU \qquad (1)$$

where $P_{(W,zone)}$ is the luminaires installed power in a zone, $\Phi_{(lum,zone)}$ the required luminous flux for a specific visual task, $\Phi_{(lum,lamp)}$ the luminous flux of the lamp when absorbs the power $P_{(W,lamp)}$, and FU a correction factor. The latter is fixed at 0.5 and is introduced based on the fact that not all lamps in a zone are turned on at the same time.

Finally, in order to introduce a BAC control in the lighting system simulation, the daylight control in type 727 was activated, introducing a minimum illuminance value for the zone. A correlation between outdoor global solar radiation on the horizontal plane (H_{gl}) and the illuminance value in the zone (I_{indoor}) with a fixed daylight factor (DF=2%) is used for this purpose:

$$I_{indoor} \approx H_{gl}\ 100\ DF \qquad (2)$$

where 100 is a conversion factor from Vartiainen [32] expressed in lm/W. Daylight controls turn lamps on whenever the I_{indoor} falls below the fixed illuminance value for a specific visual task.

3. RESULTS

This section illustrates the results for the four scenarios examined in this study.

3.1. Scenario 1. Solar thermal collector ford hot water production

Simulation results show that electricity savings can be obtained, reaching an annual solar fraction of 64%. The best results should be expected during the spring (90% reduction in April and May), while savings drops to 33-35% in winter (January and February), as reported in Table 3.

Table 3. Results from Scenario 1.

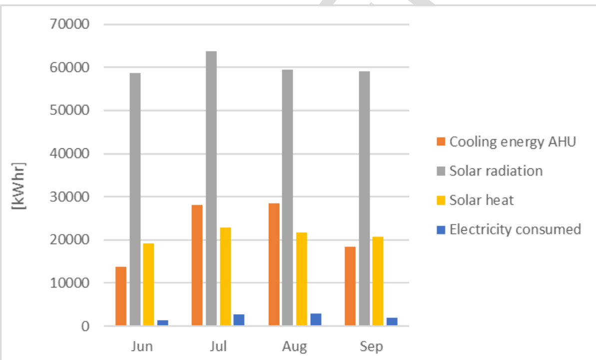
[kWh]	**Without solar collectors**	**With solar collectors**	**Reduction %**
Jan	1875	1260	33
Feb	1632	1058	35
Mar	1786	731	59
Apr	1637	154	91
May	1696	164	90
Jun	1798	599	67
Jul	1897	502	74
Aug	1713	513	70
Sep	1645	487	70
Oct	1717	654	62
Nov	1734	800	54
Dec	0	0	-
Tot	***19130***	***6922***	***64***

3.2. Scenario 2. Desiccant evaporative cooling system

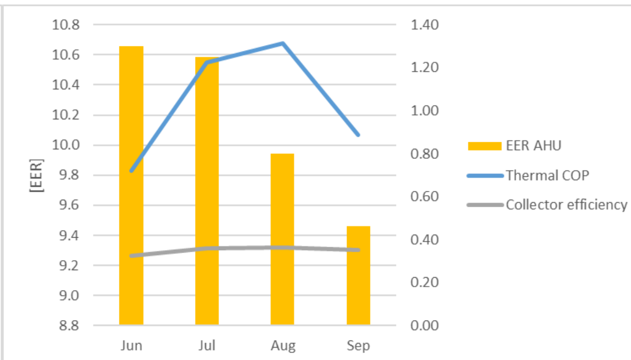
Results showed that the DEC system can efficiently contribute to heating the building if solar radiation is available, and in some cases without residual heating loads.

In the summer, the system is able to meet sensible and latent loads, providing cooling, dehumidification, and ventilation of the building. Furthermore, as well as in the previous case, this system provides DHW. Cooling energy provided by the air handling process reaches a peak power at about 60 kW, which corresponds to 30 kW of cooling energy delivered to the building. The maximum value of the absorbed electricity slightly exceeds 4 kW, in accord with the operation at maximum flow rate, whereas the global EER ranges from 12 to 14.

In the following pictures, energy performance results are reported. In particular, total cooling energy due to the air handling process, solar heat, and total electricity consumed are reported in Figure 7-a for the four months of simulation. The efficiencies of the systems are described in **Figure 7-b**.



(a)



(b)

Figure 7. Energy performance of the DEC system.

On an annual basis, the system contribution to total cooling and heating energy demand is 68% and 80% respectively (Table 4). The system can deliver 83% of the total energy required for hot water production (solar fraction in summer is 89% and 77% in winter).

Total energy saved in comparison to the currently installed heat pump consumption is about 55%.

Table 4. Annual DEC system performance.

Solar system for DHW e freescoo AHU (Aux PdC)	**Summer**	**Winter**	
Solar fraction DHW	89%	77%	
Aux DHW (Heat Pump)	1060	1713	kWh
Total solar energy	123237	95510	kWh
Total cooling/heating energy produced by the AHU	88695	24892	kWh
Total cooling/heating energy delivered to the building	42618	14017	kWh
Seasonal EER	11.1	14.1	
Total sensible loads	62270	15553	kWh
Total latent loads	22849	1055	kWh
Residual sensible loads	8315	3065	kWh
Residual latent loads	19324	0	kWh
Total residual loads	27639	3065	kWh
	32%	**18%**	
Electricity consumed			
Electricity consumed by the AHU	8750	2161	kWh
Electricity consumed by the HP for air conditioning	11607	1287	kWh
Electricity consumed by the HP for DHW	445	719	kWh
Total electricity consumed	20802	4168	kWh
Total annual electricity consumed	24969		kWh
HP for DHW and air conditioning (current state)			
Total electricity consumed	35745	19130	kWh
Total energy saving		**55%**	

3.3. Scenario 3. Photovoltaic system

In this scenario, a parametric study of performance was performed by changing the storage capacity as follows:

- run 1: capacity = 0 kWh;
- run 2: capacity = 30 kWh;
- run 3: capacity = 50 kWh;
- run 4: capacity = 100 kWh;
- run 5: capacity = 150 kWh;
- run 6: capacity = 300 kWh.

The amount of energy extracted from the grid in each sub-scenario is shown in Figure 8 and Table 5. This figure shows that increasing the capacity of the battery leads to a reduction of the energy extracted from the grid (very large in the winter months and not relevant in the summer months). Furthermore, the capacity of the battery pack needed to significantly decrease energy consumption in the summer months is 100 kWh, which is very expensive to install. As shown in Table 5, larger battery capacities do not lead to any further benefit.

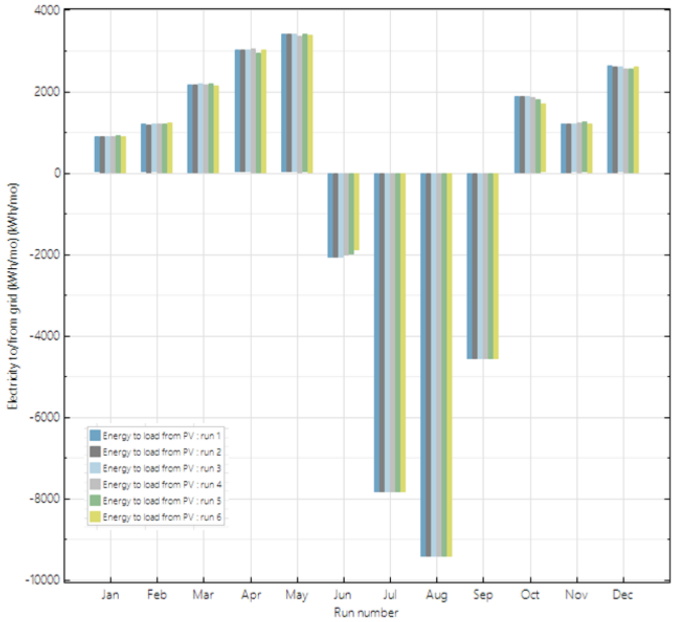


Figure 8. Monthly summary of the electricity from/to the grid.

Table 5. Summary of the results varying the capacity of the electrical storage.

Capacity [kWh]	**Energy from the grid [kWh]**	**Percentage deviation with respect to annual needs %**
0	33219	61%
30	29783	54%
50	27801	51%
100	24658	45%
150	24166	44%
300	24009	44%

Finally, as expected, the capacity of the electrical storage system does not affect the amount of energy directly delivered from the PV system to the heat pump, reaching a peak of self-consuming energy in the summer months (Figure 9). However, in the same months, the size of the PV plant does not cover the energy demand, also showing the maximum withdrawal from the grid (Figure 10).

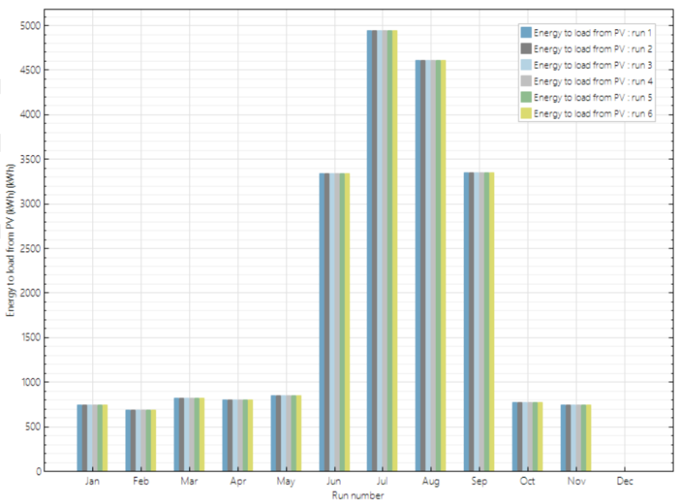


Figure 9. Monthly summary of the electricity produced by PV plant and consumed by the heat pump.

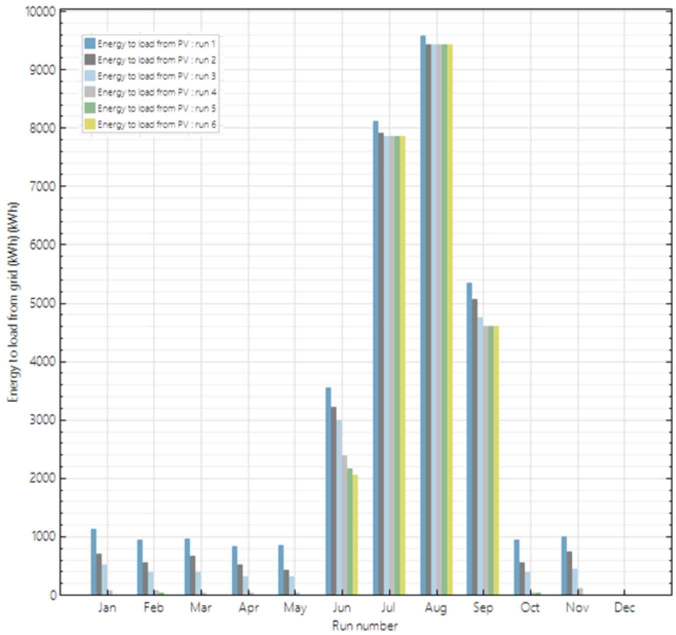


Figure 10. Monthly summary of the electricity from the grid consumed by heat pump.

3.4. Scenario 4. Building automation control system

Looking at the LED and BAC retrofit scenario, and taking into account the data measured by El.M_2, it is possible to highlight the following points:

- with respect to the actual electricity consumption for lighting, replacing halogen lamps with LED leads to 65% energy savings and to 68% savings when illuminance control is activated;
- with respect to the actual electricity consumption for lighting and appliances, changing lamps from halogen to LED leads to 27% energy savings and to 29% savings when illuminance control is on;
- the peak of consumption decreases from 18 kW to 12 kW for the LED scenario, and to 11 kW for the LED and illuminance control scenario;
- integrating BAC technology into the system reduces energy consumption by about 6% with respect to overall electricity consumption, with a peak reduction from 18 to 15 kW.

3.5. Impacts on the hotel's electric load profile

An important effect of implementing the proposed measures is the modification of the shape of the hotel's daily electric load profile. As shown in the following figures, both the maximum power peak and the energy consumption of the hotel during peak price hours decrease, with benefits for the end user as well as for the entire power distribution grid.

Figure 11 to Figure 17 show a comparison of the hotel's actual overall load profile on a typical summer day (scenario SC.0), evaluated as the sum of daily consumption for general use and for air-conditioning, calculated for each of the scenarios listed below:

- SC.1: solar thermal system integrating the existing domestic hot water (DHW) production system;
- SC.2: DEC system with solar thermal collectors for air conditioning and also DHW production;
- SC.3: 30 kWp grid-connected PV system;
- SC.4: 30 kWp grid-connected PV system with a 50 kWh battery storage system;
- SC.5: replacement of traditional low-efficiency lamps with LED lamps;

- SC.6: replacement of traditional low-efficiency lamps with LED lamps and artificial lighting ON/OFF control as function of the natural lighting;
- SC.7: replacement of traditional low-efficiency lamps with LED lamps and installation of BAC systems for managing lighting system and flexible loads.

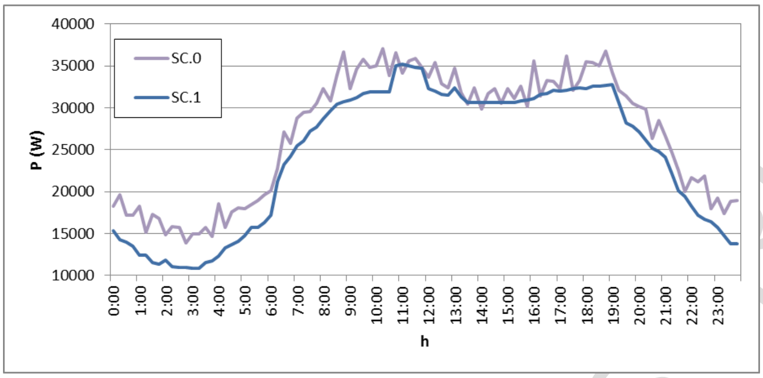


Figure 11. Comparison of the daily load profiles in SC.0 and SC.1

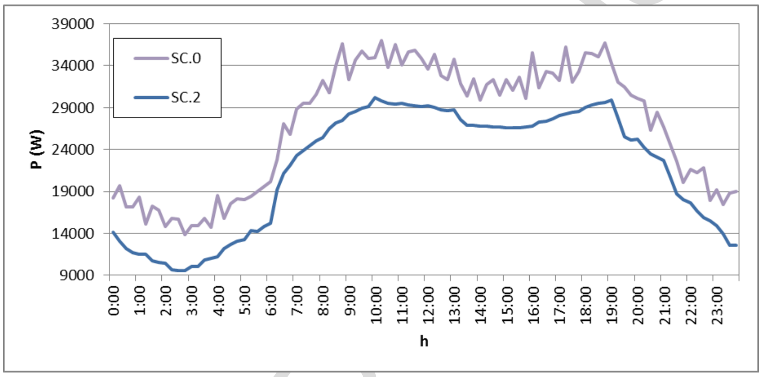


Figure 12. Comparison of the daily load profiles in SC.0 and SC.2

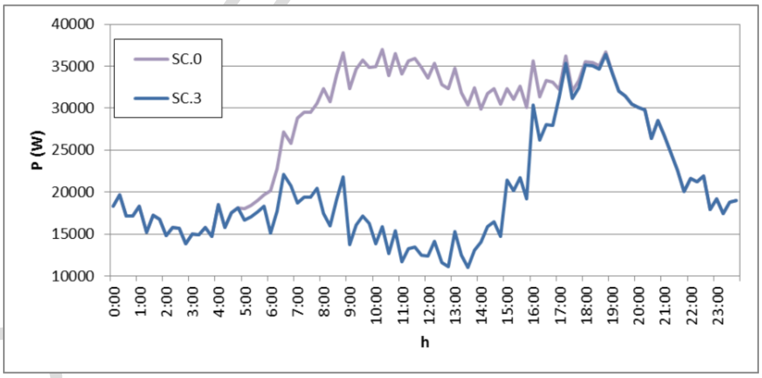


Figure 13. Comparison of the daily load profiles in SC.0 and SC.3

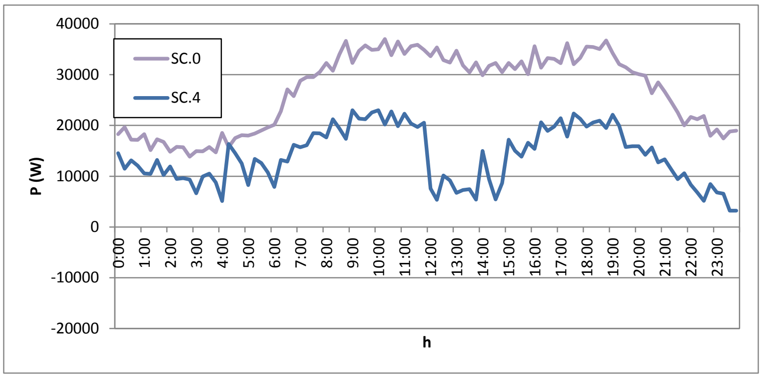


Figure 14. Comparison of the daily load profiles in SC.0 and SC.4

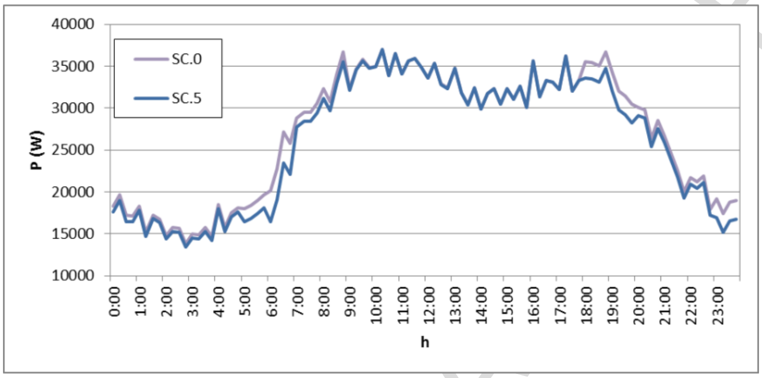


Figure 15. Comparison of the daily load profiles in SC.0 and SC.5

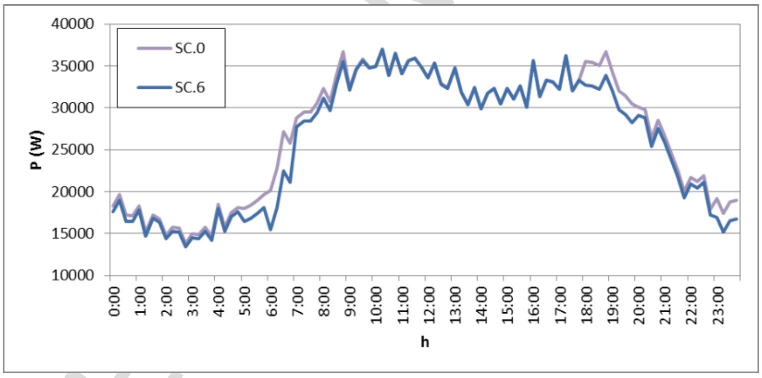


Figure 16. Comparison of the daily load profiles in SC.0 and SC.6

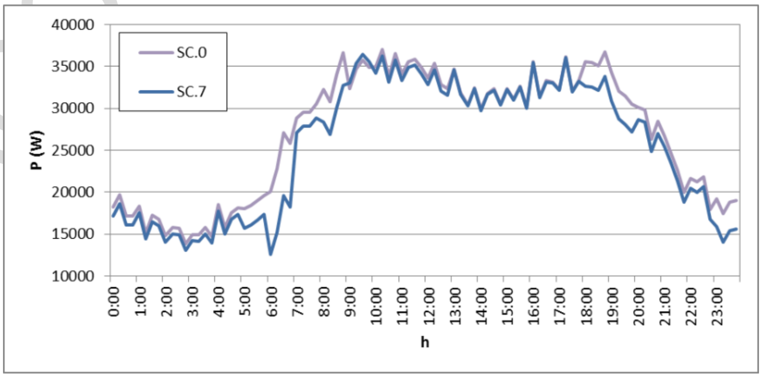


Figure 17. Comparison of the daily load profiles in SC.0 and SC.7

Table 6 summarizes the results of the analysis in terms of reduction of the summer daily power peak.

Table 6. Daily power peaks in scenarios SC.0-SC.7.

Scenario	Power peak [kW]	Power peak reduction with respect to SC.0 [%]
SC.0	37.03	-
SC.1	35.20	4.95
SC.2	30.18	18.51
SC.3	36.39	1.72
SC.4	23.01	37.86
SC.5	37.02	0.03
SC.6	37.02	0.03
SC.7	36.49	1.47

It is worth highlighting that the installation of ST and PV systems (scenarios SC.1-SC.4) produce the most significant changes of the shape of the daily load profile and considerably reduce the overall daily electricity demand. The presence of the storage system, moreover, it is able to considerably reduce the daily power peak with beneficial effects on the electric distribution grid that supply the hotel. This implies that making solar system widely available to the public, also thanks to specific economic support measures, could lead to a significant reduction of the power losses in feeders and transformers and a consequent increase of the generation and distribution efficiency of the grid.

4. **CONCLUSION**

The present work introduces a method to assess the potential impact of energy retrofit strategies in the hotel sector, and was applied to a representative island called Lampedusa. The energy consumption on small islands highly differs from mainland cases. For that reason, official statistics were put side-by-side with data gathered from a questionnaire campaign and with data from an on-site survey. Experimental data regarding hotel energy consumption is rarely available and is difficult to get, even though model validation with respect to hourly and monthly load profile is very important, even more so in the specific small island context in which energy consumption is extremely affected by tourist flow. For that reason, a method based on model validation by monthly consumption data from the local utility was applied and compared to experimental data, showing high reliability of results. The analysed case study is a typical hotel in Lampedusa (Italy) chosen according to statistical data. The existing plant that powers air conditioning and DHW (based mainly on a HPWH) readily permits different energy-retrofit scenarios based on RES technology integration. At the same time, ICT and BAC solutions for generic electric uses were investigated, and effects on the load diagram of the proposed scenarios were highlighted. Results on a yearly basis show:

- in Scenario 1, a 64% reduction of electricity consumption for DHW production and 13% for the HPWH;
- in Scenario 2, a 55% reduction of overall electricity consumption of the existing HPWH;
- in Scenario 3, an optimal sizing of the electricity storage coupled with the PV plant reduced electric energy demand from the local grid of the HPWH up to 61%;
- in Scenario 4, LED lighting systems led to an energy saving final electricity uses of about 30%, while the BAC system allowed for additional 6% savings.

It should be noted that solar system integration could certainly reduce the load peak from the grid as well as reduce general energy consumption. Scenario 1 is specifically the least invasive with respect to the hotel plant system. This system previews the installation of solar thermal collectors to assist existing

HPWH and reduces electricity consumption for DHW production by 64% with a moderate impact on total HPWH electricity consumption (13%).

Scenarios 2 and 3 propose two alternative solutions to the actual air conditioning and DHW production systems, both exploiting solar energy source (respectively solar thermal collectors in combination with a DEC AHU, and photovoltaic panels in combination with the actual HPWH). Comparable results are highlighted for DHW and air conditioning electricity saving. Scenario 2 is preferable; indeed, restrictions regarding the installation of electric storage in the PV scenario should be carefully considered. Finally, Scenario 4 shows the lowest energy saving values but proposes a zero-impact solution at a landscape level that could be easily applied wherever regulatory restrictions for small islands exist (as outlined in the introduction).

The generalisation of the results to the whole island territory and to other small islands in Italy is the focus of another ongoing study being conducted by the University of Palermo on behalf of ENEA.

REFERENCES

[1] Beccali, M., Bonomolo, M., Di Pietra, B., Ippolito, M.G., La Cascia, D., Leone, G., Lo Brano, V., Monteleone, F., Zizzo, G. Characterization of a small Mediterranean island end-users' electricity consumption: The case of Lampedusa. Sustainable Cities and Society 35 (2017), 1-12.

[2] Beccali, M., Ciulla, G., Di Pietra, B., Galatioto, A., Leone, G., Piacentino, A., Assessing the feasibility of cogeneration retrofit and district heating/cooling networks in small Italian islands. Energy 141 (2017) 2572-2586

[3] Calise, F., Dentice d'Accadia, M., Macaluso, A., Vanoli, L., Piacentino, A., A novel solar-geothermal trigeneration system integrating water desalination: Design, dynamic simulation and economic assessment. Energy 115 (2016) 1533-1547

[4] Calise, F., Macaluso, A., Piacentino, A., Vanoli, L., A novel hybrid polygeneration system supplying energy and desalinated water by renewable sources in Pantelleria Island. Energy 115 (2016) 1533-1547

[5] Segurado, R., Costa, M., Duic, N., Carvalho, M.G., Integrated analysis of energy and water supply in islands. Case study of S. Vicente, Cape Verde. Energy 92 (2015) 639-648

[6] Kuang, Y., Zhang, Y., Zhou, B., Li, C., Cao, Y., Li, L., Zeng, L., A review of renewable energy utilization in islands. Renewable and Sustainable Energy Reviews 59 (2016) 504–513.

[7] Erdinc, O., Paterakis, N.G., Catalão, J.P.S., Overview of insular power systems under increasing penetration of renewable energy sources: Opportunities and challenges. Renewable and Sustainable Energy Reviews 52 (2015) 333–346.

[8] B. Möller, K. Sperling, S. Nielsen, C. Smink, S. Kerndrup, Creating consciousness about the opportunities to integrate sustainable energy on islands. Energy 48 (2012) 339-345.

[9] Ilkan, M., Erdil, E., Egelioglu, F., Renewable energy resources as an alternative to modify the load curve in Northern Cyprus. Energy 30 (2005) 555–572.

[10] Neves, D., Silva, C.A., Connors S., Design and implementation of hybrid renewable energy systems on micro-communities: A review on case studies. Renewable and Sustainable Energy Reviews 31 (2014) 935–946.

[11] Polanco González, J., Yousif, C., Prioritising energy efficiency measures to achieve a zero net-energy hotel on the island of Gozo in the central Mediterranean. Energy Procedia 83 (2015) 50 – 59.

[12] Beccali, M., La Gennusa, M., Lo Coco, L., Rizzo G., An empirical approach for ranking environmental and energy saving measures in the hotel sector. Renewable Energy 34 (2009) 82–90.

[13] Ciriminna, R., Pagliaro, M., Meneguzzo, F., Pecoraino, M., Solar energy for Sicily's remote islands: On the route from fossil to renewable energy. International Journal of Sustainable Built Environment 5 (2016) 132–140.

[14] Ferrari, S., Zagarella, F. Costs assessment for building renovation cost-optimal analysis (2015) Energy Procedia, 78, pp. 2378-2384. Cited 5 times.
[15] Ferrari, S., Beccali, M., Energy-environmental and cost assessment of a set of strategies for retrofitting a public building toward nearly zero-energy building target. Sustainable Cities and Society 32 (2017) 226-234.
[16] Ferrari, S., Zanotto, V. Office buildings cooling need in the Italian climatic context: Assessing the performances of typical envelopes (2012) Energy Procedia, 30, pp. 1099-1109.
[17] Zambrana-Vasquez, D., Aranda-Uson, A., Zabalza-Bribia, I., Janez, A., Llera-Sastresa, E., Hernandez, P., Arrizabalaga, E., Environmental assessment of domestic solar hot water systems: a case study in residential and hotel buildings. Journal of Cleaner Production 88 (2015) 29-42.
[18] Calise, F., Dentice d'Accadia, M., Damian Figaj, R., Vanoli, L., A novel solar-assisted heat pump driven by photovoltaic/thermal collectors: Dynamic simulation and thermos-economic optimization. Energy 115 (2016) 1592-1601.
[19] Chen, Y., Yang, H., Luo, Y., Investigation on solar assisted liquid desiccant dehumidifier and evaporative cooling system for fresh air treatment. Energy 143 (2018) 114-127.
[20] Hong, S. H., Kim, S. H., Kim, G. M., Kim, H. L., Experimental evaluation of BZ-GW (BACnet-ZigBee smart grid gateway) for demand response in buildings. Energy 65 (2014) 62-70.
[21] D. Croce, F. Giuliano, I. Tinnirello, A. Galatioto, M. Bonomolo, M. Beccali, G. Zizzo, Overgrid: A Fully Distributed Demand Response Architecture Based on Overlay Networks, (2017) IEEE Transactions on Automation Science and Engineering, 14 (2), art. no. 7750612, pp. 471-481.
[22] Beccali, M., Bonomolo, M., Ippolito, M.G., Lo Brano, V., Zizzo, G. Experimental validation of the BAC factor method for lighting systems (2017) Conference Proceedings - 2017 17th IEEE International Conference on Environment and Electrical Engineering and 2017 1st IEEE Industrial and Commercial Power Systems Europe, EEEIC / I and CPS Europe 2017
[23] Ala, G., Cosentino, V., Di Stefano, A., Fiscelli, G., Genduso, F., Giaconia, G.C., Ippolito, M. G., La Cascia, D., Massaro, F., Miceli, R., Romano, P., Spataro, C., Viola, F., Zizzo, G., "Energy Management via Connected Household Appliances", Publisher: McGraw-Hill, Milan (Italy), 2008, p. 1-158, ISBN: 978-88-386-6676-6.
[24] Di Silvestre, M.L., La Cascia, D., Riva Sanseverino E., Zizzo G., Improving the energy efficiency of an islanded distribution network using classical and innovative computation methods, Utilities Policy Vol. 40, pp. 58-66, 2016.
[25] Beccali, M., Leone, G., Piacentino, A., Ciulla, G., Lo Brano, V., Galatioto, A., Bonomolo, M. , "Efficientamento energetico isole minori non connesse al sistema elettrico nazionale: stima del potenziale termico ai fini dello sviluppo di reti di teleriscaldamento e raffreddamento", in http://www.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema-elettrico/risparmio-energia-settore-civile/2014/rds-par2014-020.pdf .
[26] Zizzo, G., Beccali, M., Bonomolo, M., Di Pietra, B., Ippolito, M.G., La Cascia, D., Leone, G., Lo Brano, V., Monteleone, F., A feasibility study of some DSM enabling solutions in small islands. The case of Lampedusa. Energy 140 (2017) 1030-1046.
[27] http://dati-censimentopopolazione.istat.it/Index.aspx?lang=en
[28] Finocchiaro, P., Beccali, M., Innovative Compact Solar Air Conditioner based on Fixed and Cooled Adsorption Beds and Wet Heat Exchangers. Energy Procedia 48 (2014) 819-827.
[29] Finocchiaro, P. Marco Beccali, Andrea Calabrese, Edoardo Moreci, Second Generation of Freescoo Solar DEC Prototypes for Residential Applications, In Energy Procedia, Volume 70, 2015, Pages 427-434, ISSN 1876-6102, https://doi.org/10.1016/j.egypro.2015.02.144.
[30] https://sam.nrel.gov/
[31] UNI EN 12464-1:2011 "Light and lighting – Lighting of workplaces. Part 1: Indoor work places"
[32] Vartiainen, E., A comparison of luminous efficacy models with illuminance and irradiance measurements. Renewable Energy 20 (2000) 265-277.

Highlights

1. A representative hotel on Lampedusa Island (ITALY) has been chosen
2. Simulations on actual hotel consumption are set up
3. Renewable Energy Source retrofit scenarios are proposed and evaluated by simulations
4. Solar options provide the most significant benefits